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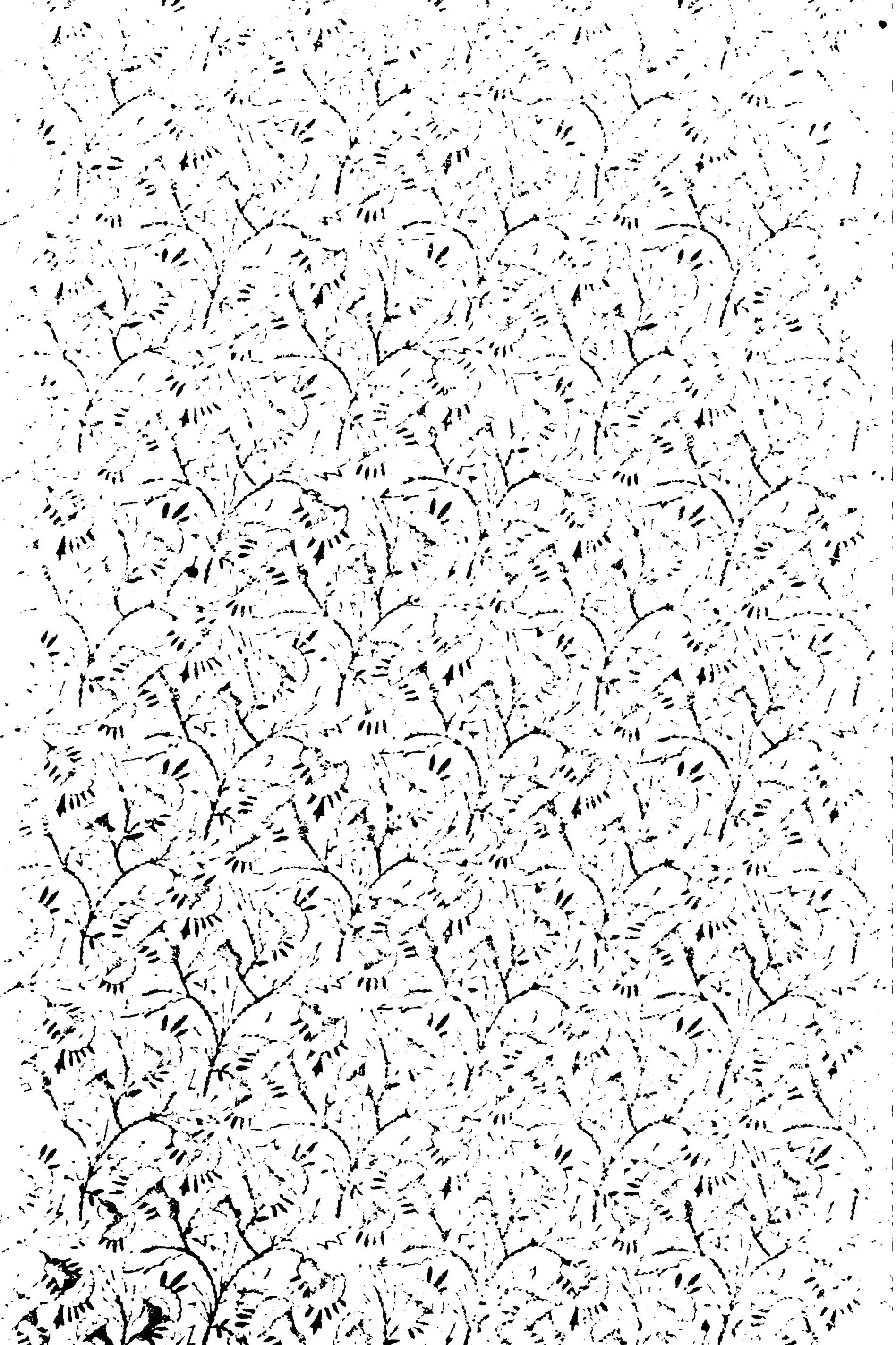

THE CYCLOPÆDIA

OF

ELECTRICAL ENGINEERING

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Thomas Alva Edison.

INVENTOR OF THE QUADRUPLEX TELEGRAPH &c.&c.

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Electrical Engineering

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WITH ITS PRACTICE AND ACHIEVEMENTS FROM THE
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WITH NEARLY 600 *ILLUSTRATIONS*
AND TWO PHOTOGRAVURE PORTRAITS ON STEEL

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CHAPTER XIII.—CONTINUED.

FARADAY'S TRANSFORMER.

THE lines of force of the current in the primary coil were, of course, conducted by the iron ring round through the secondary coil, and the sudden cutting of this coil by them gave rise to the observed currents. As might be expected, however, a great many of the lines of force did not reach the secondary coil, and Faraday obtained a more violent deflection with the same primary current and shorter lengths of wire, by so arranging the two circuits that nearly all the lines of force generated were able to cut the secondary circuit. He disconnected the two helices which in the previous experiment were used as a secondary circuit, and in their place took two of the three superposed helices on the other half of the ring, joining them in series and to the galvanometer. The battery was then joined to the third helix, which formed the primary circuit, and although the lengths of wire were so much shorter, rather better effects were obtained, because of the increase in the percentage of the lines of force usefully employed. Had Faraday supplied the primary circuit with a rapidly alternating current, he might have obtained an alternating current of half the strength, and of corresponding higher electro-motive force in the secondary circuit; but his galvanometer would not have indicated the presence of this current if the reversals were too rapid to give the needle time enough to move with each pulsation. By using one helix for the secondary and two for the primary, the secondary current might have had twice the strength of the primary.

We may repeat that a transformer should be so designed that it can effect the required reduction from high to low E. M. F. with as little waste as possible. The wires of the two circuits should be so disposed with respect to each other that the greatest possible number of the primary current's lines of force cut the secondary circuit, while if iron is employed to assist in this direction, care must be taken that but little energy is lost in it by eddies and hysteresis.

To reduce the loss by eddies the iron must be laminated at right angles to the path they tend to take, while it must be left, as far as possible, continuous in the direction of the lines themselves. Loss by hysteresis requires careful consideration; it increases with the rapidity with which the current alternates, and with the density of the lines of force through the iron. Consequently care should be taken in deciding upon the rate of alternation, and the mass of the iron to be employed; but these are matters upon which reliable experimental research upon a practical scale is much needed. Attention must also be devoted to such points as economy of construction, efficiency of insulation, and the facilities for the escape of the heat which is the evidence of the inevitable loss during the conversion.

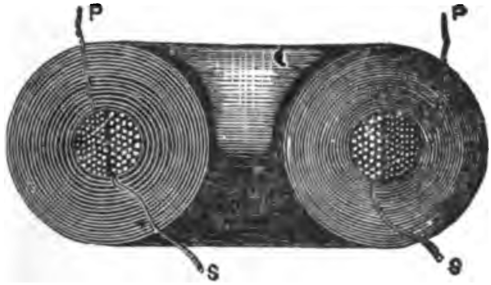
Perhaps the simplest type of practical transformer is a slight modification of Faraday's original one. An iron core might be entirely overwound with a few layers of thick insulated copper wire to form the secondary circuit, and a number of layers of thinner wire then wound over this to form the primary. Resistance is of comparatively small importance in the primary coil, but it must be kept low in the other coil, because that carries a heavy current.

It might be thought that some advantage would be derived by interlacing the two coils so as to bring them into closer proximity, but this cannot be done in practice on account of the difficulty in maintaining effective insulation. The potential difference between even the extreme ends of the secondary coil is low, and little trouble is experienced in insulating this coil, but quite the reverse obtains with the primary. The wire-covering must not be too thick, otherwise the space occupied becomes great, but the utmost care must be taken to avoid bringing into proximity any convolutions separated from each other by a long length of wire, and therefore having a high potential difference between them. And as in practice the secondary circuit is sometimes led into places where i can be and is handled, every precaution must be taken to effectually insulate it from the primary. For this reason the two coils are never interlaced, but are wound separately, with effective insulation between them.

The simplest way of laminating the iron core, is to build it up of thin iron wire, in exactly the same manner as the core of a Gramme ring. In fact, a Gramme ring armature having a large number of convolutions can be readily turned into a very fair transformer, by using two or three equidistant sections for the secondary coil, and the remainder in series for the primary. Transformers are sometimes so constructed in sections, but the usual way is to wind the wires spirally in two continuous coils.

The rapid reversals of magnetisation which take place, quickly heat the iron core, however well it is laminated. This heat must escape, and since the iron is enveloped by copper, the heat must be imparted to the copper before it can reach the external air. This heating of the conductor is very undesirable, and for this and several other reasons it is preferable to place the iron outside instead of inside the wire, the position of the iron being quite immaterial, provided it can act effectively in leading the lines of force through the desired paths.

FIG. 233.



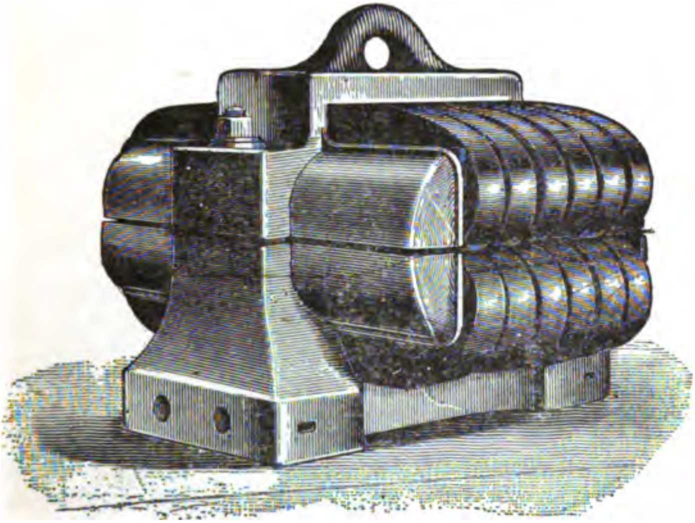
In fig. 233 is illustrated one method of constructing such a transformer. Its external appearance is that of a massive ring of small internal diameter, and in the figure is shown a section taken through a diameter, at right angles to the plane of the ring. The primary and secondary coils are each wound in a single coil, and lie close together concentrically. They are wrapped round with an insulating material, and over this is wound spirally an enormous quantity of soft iron wire. The inner coil of thick wire, s s, is the secondary, while the primary coil of thinner wire, P, P, lies outside it, and it will be observed that the depth of the layer of iron wire is about equal to the diameter of the compound coil of copper wire. Such a transformer gives fairly good results, for nearly all the primary lines of force extend out to the massive iron shell, and in so doing cut the secondary. But it is an extremely tedious and expensive piece of apparatus to make on a large scale, on account of the slow process of winding the enormous length of iron wire. Further, if a fault should occur, and faults *will* occur, it becomes necessary to remove the whole of the iron wire before the coils can be got at, to remove the fault.

Consequently large transformers are not made in the manner illustrated, although in most cases the principle is the same. The apparatus usually consists of two coils of wire, nearly oblong in shape, lying side by side, with an easily fixed, and easily removable laminated iron covering.

About thirty-three years ago a first-rate method of constructing a large transformer was patented by C. F. Varley, which may be regarded as a combination of the two types mentioned. He took a bundle of iron wires of approximately equal lengths, and over this bundle wound the primary and secondary coils. These coils were placed in the middle of the bundle, and extended along it for a distance equal to one-third of its length, so that the iron wires protruded from each end to a distance equal to the length of the coil. The ends of the iron wires were then bent round over the coils, so as to meet and overlap each other, thus completely encasing the coils with iron, except at one place through which the connecting wires were led.

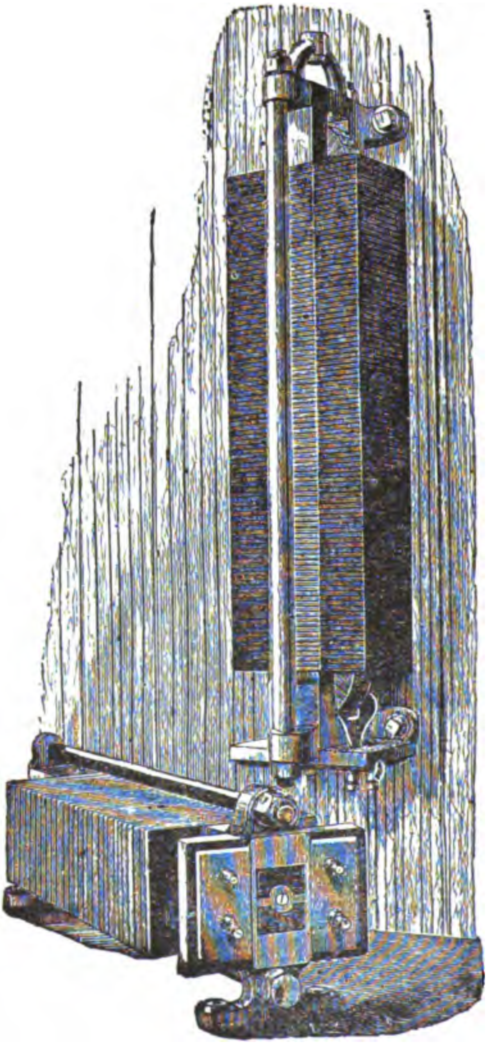
But the necessity for large transformers did not then exist, and the method was scarcely at all employed. It is, however, somewhat extensively used at the present time, because of the ease with which the iron shell can be fixed or removed. The highest practical development of this type is seen in the Ferranti transformer, which is now doing heavy work in London. A general view of a Ferranti transformer, designed to receive about fifteen electrical horse-power at a high potential difference, and yield a large percentage thereof at a lower potential difference, is given in fig. 234. A quantity of hoop-iron, divided into six bundles, forms the base upon which the essential parts of the apparatus are built up. Over the middle of this is wound a layer of thick insulated wire or strip, to form the secondary coil. The finer wire to form the primary coil is wound on a convenient frame in sections, which are slipped over the secondary, and carefully insulated from it and from the iron. The protruding ends of the hoop-iron bundles are then bent over the coils, half at the top and half at the bottom, as shown in the figure, their ends meeting and overlapping for a short distance. The whole is then placed in a cast-iron framework made in two pieces and securely bolted together, the portions of the coils not enveloped by the laminated iron being covered, mainly for purposes of protection, by large shields, which are cast with the frames.

FIG. 234.



The lamination is, of course, not so effective as if iron wires were employed, or as if the iron bands were placed edge-on to the direction of the lines of force; but the construction is very easy, and the spaces left between the bundles of hoop-iron greatly facilitate the escape of the heat developed.

FIG. 235.



The magnetic circuit of many transformers is now built up of a number of flat plates of sheet iron, placed so that the plane of the sheet shall be as far as possible parallel to the direction in which the lines of force are thrust through the iron. They are usually insulated by a thin coating of varnish, or by paper, or sometimes calico, and the devices by which such plates may be cheaply made and placed in position are very numerous. As they differ but little in principle, we need select only two patterns for description.

Two general views of the Mordey type of transformer are given in fig. 235. The thin iron plates are oblong stampings, and an oblong strip is stamped out of the middle of each, exactly equal in length to the breadth of the original plate. When this strip is placed across the middle of the plate its ends just reach to the edges thereof, leaving two rectangular openings, one on either side of the strip, which are subsequently occupied by the wire. The primary and secondary coils are wound separately on a frame of such a shape that each coil consists of two parallel straight portions, with rounded ends, the section being rectangular and of such size that the two coils when placed one over the other just fill the openings in the plates previously referred to. The larger stampings are slipped one by one over the coils, alternating with the narrower strips which are threaded through the coils, the coils, with the exception of their rounded ends, being in this way completely encased in iron When the requisite number of plates have been placed in position, they are clamped tightly together between two cast-iron end-plates, held by bolts and nuts, as shown in the figure. The apparatus can either be fixed to the wall, suspended from the roof, or screwed down to the floor, as may be convenient.

There is a small air-space between the plates, whence the surface available for dissipation of heat is considerable.

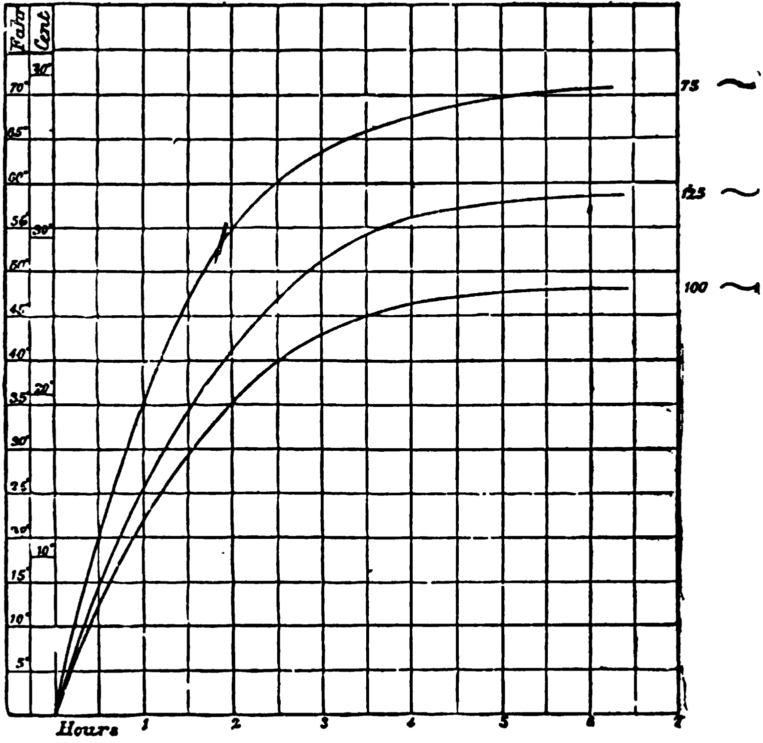
If a transformer is not well-designed or is improperly employed, the amount of power lost and appearing as heat may become a very serious matter. If the quantity of iron is so small that the magnetic induction through it becomes too high, then the loss by hysteresis is great; and a like result follows if the magnetisation is too rapidly reversed. Not only should the mass of iron employed be ample, but it should be so disposed that the cooling surface is also great; and if this latter point is attended to no difficulty should arise in working at an induction of about 7,000 C.G.S. lines.

Since in any case the loss due to hysteresis increases with the rapidity of reversal, it might be thought that the lower the rate of alternation employed the better. In practice the rate of alternation of the current supplied to transformers varies from about 50 to 130 complete alternations per second, and although the particular rate adopted *may* in every case be best suited to the particular apparatus, or to the conditions of working, there would certainly appear to be need for further inquiry into the matter.

Mr. Mordey has recently performed a lengthy series of experiments to determine the rate of alternation best suited to his own transformer, the method adopted being to discover at what rate the least heat was developed in the apparatus. The rise in temperature was measured by means of a sensitive thermometer, the bulb of which was placed on the iron, and protected from external influence by a covering of cotton waste. A similar thermometer, placed a short distance away, indicated the temperature of the room, which, however, varied but slightly. Each test was con-

FIG. 236.

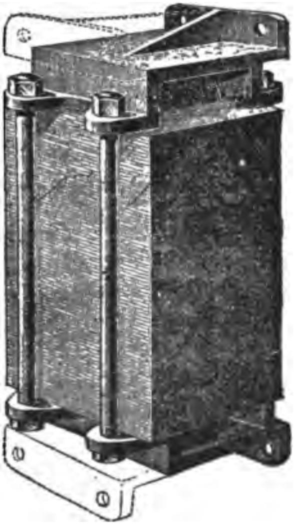
Rise of Temperature of Transformers at various periodicities.



tinued for six and a half hours, the rate of alternation being kept constant during that time; while the primary and secondary potential differences, and the load on the secondary circuit (consisting of a number of incandescent lamps), were the same throughout.

The readings obtained during three tests are plotted in the three curves in fig. 236, and the result is somewhat surprising. The lowest curve was that obtained with 100, and the middle one with 125 alternations per second, the loss at the higher rate being considerably the greater. This is precisely what one would expect, but it was found that the loss was still greater at the lowest rate, viz. 75 alternations per second; and the highest curve represents the results obtained with this rate. So that, evidently, there is a best rate for every transformer, any increase or decrease in which would entail an increased loss of power by heat. For his own apparatus Mr. Mordey has decided upon 100 alternations per second. There is but little doubt that these results are thoroughly reliable, for it is also the experience in practice that an abnormal rise in temperature quickly occurs if the normal rate of alternation happens to be considerably increased or reduced.

FIG. 237.



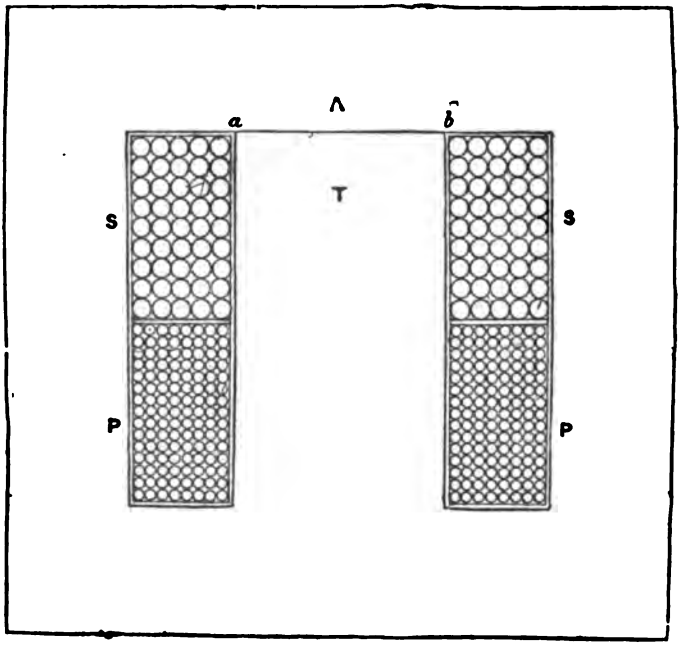
The explanation suggested by Dr. Fleming is probably correct, that, at any rate above the normal one, the loss is principally due to hysteresis, while at lower rates more time is given for the eddy currents to penetrate deeper into the core and so waste more power.

In fig. 237 is illustrated the transformer designed and constructed by Mr. J. G. Statter. A section is given in fig. 238.

The iron stampings (fig. 238) are nearly square in shape, and two oblong pieces are stamped out of each to form the spaces in which the wire is placed. S S is the thick secondary coil, while

P P is the primary, and these two coils are wound to the proper shape on a suitable mould or frame, and placed one over the other as indicated in the figure. The strip T of each stamping is divided from the plate at one end, along the line *a b*. In building up the transformer the tongue T thus formed is bent at right angles to the plate, which can then be slipped over the coils. and the tongue bent back into its proper position. A large number of plates being similarly slipped on, the wire is surrounded on all sides by iron.

FIG. 238.



Two strong cast-iron plates, and four bolts, hold the plates in position, the plates forming a protective covering to the otherwise exposed ends of the coils. They are also provided with flanges and bolt-holes for fixing the transformer in any required position. The end plates are frequently fitted with an extra flange, as indicated by the dotted lines, to which is screwed a wooden case, with a glass front, providing accommodation for a safety fuse, and also a double-pole switch, by means of which both wires leading to the primary coil can be simultaneously disconnected.

These transformers are made in a variety of sizes, but the most frequent are those capable of transforming down from 2,000 volts to 100 volts, 2,000 to 50, 1,000 to 100, and 1,000 to 50.

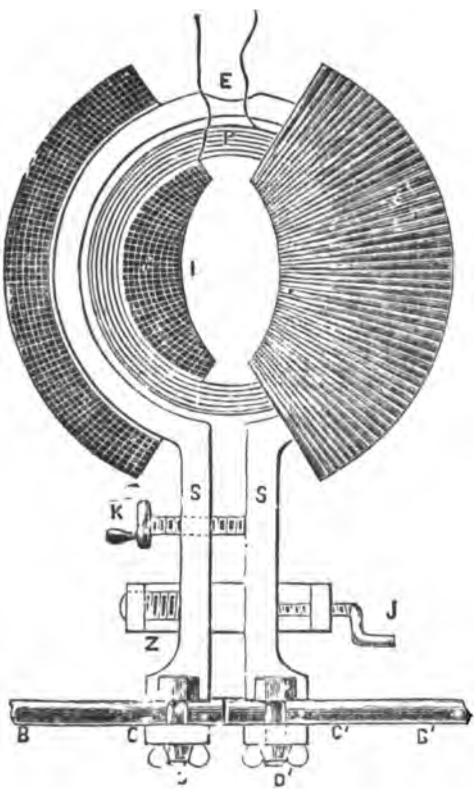
Transformers have been put to a novel and interesting use by Prof. Elihu Thomson, who employs them for the purpose of obtaining the very heavy currents, which are required in his method of electric welding. This method consists in placing the two pieces of metal required to be welded end to end, and subjecting them to moderate pressure against each other. A very heavy current is then passed through them, and as they make imperfect contact at their opposing surfaces, considerable resistance is there offered to the passage of the current, and a very intense heat is consequently developed at the point where it is required to make the weld. If the current is sufficiently strong, the opposing surfaces get white hot, and being pressed together they unite perfectly, bulging out, however, round the edges. It is necessary that the surfaces should be perfectly clean, and a flux, the composition of which depends upon the nature of the metals to be welded, is usually employed to prevent the oxidation of the surfaces and so render the weld more perfect. In the case of iron, a little borax is sprinkled over the ends of the rods.

But in order to sufficiently raise the temperature of thick rods of metal, enormous currents are required; for instance, a current of about 20,000 amperes would be required to weld a steel rod seven-eighths of an inch thick. It will readily be understood that in such a case the resistance of the current generator must be extremely small, otherwise the power absorbed in it would amount to many horse-power.

Secondary batteries might be employed for the smaller currents, but the most economical method is to generate an alternating current by means of a dynamo, at a fairly high E.M.F., and, reducing this to a lower E.M.F. by means of a transformer, obtain at the same time an increase in the current strength.

Various types of transformer have been employed for the purpose, one form being illustrated by the diagram in fig. 239. The primary coil, P. is composed of a number of turns of wire, wound in a circular coil; the secondary consists of a single massive copper strip, S S, bent into a circular form, and placed concentrically with the primary coil. Over the two coils is wound a quantity of iron wire, I I, in two masses, space being left between them on one side, for the passage of the wires leading to the primary coil, and on the other side, to bring out the massive straight bars forming the ends of the primary coil. The bars can be held open by means of the screw at K; their extremities being provided with massive clamps, C C′, in which the pieces to be welded, B B′, are fixed. A spiral spring, at Z presses the ends together, the pressure being regulated by means of the screw at J.

FIG. 239.



For ordinary work a current of 12,000 amperes is the maximum required, and in such a case the power is usually supplied to the primary at an E.M.F. of about 600 volts, the current being twenty amperes. A certain amount of this power is, of course, lost during the conversion; but a current of 12,000 amperes at an E.M.F. of nearly one volt can be obtained in the secondary circuit.

It is important to observe the reason for most of the heat being developed at the proper point. When the current is started in the secondary circuit, the resistance at the junction is far greater than the resistance of the whole of the remainder of the circuit; consequently the fall of potential there is comparatively very great, that is, nearly the whole of the power appearing in the secondary is expended in overcoming the resistance at the opposing surfaces. These surfaces get hot, and being pressed together, they then make much better contact. The rise in temperature, however, considerably increases the resistance, and consequently the expenditure of power at this point is still proportionally great. The ease with which the heat can be confined to any particular locality constitutes one great advantage of the method. It is usual to quickly remove the welded pieces, and hammer the joint into shape on an anvil. The clamps make contact with a large surface, to avoid, as far as possible, the introduction of resistance, and they are so designed that the removal of the welded rods can be speedily effected.

The voltmeter illustrated in fig. 106 was specially constructed for use with one of these transformers, the potential difference in the secondary circuit ranging up to about 2·5 volts.

There are two distinct methods of distributing power to a number of transformers, each of which has several important advantages to recommend it. First, the whole of the transformers may be joined in series, and a constant current sent through the whole of the primary coils. Secondly, they may all be connected in parallel between two main leads, which are kept at a constant potential difference, so that the difference of potential between the ends of all the primary coils is always the same.

The former is in some cases the more economical as regards main conductors, for the maximum current in them is only equal to that supplied to one transformer, and is the same when the maximum amount of work is being done as it is during any smaller demand. But a generator is required which will supply a constant (alternating) current, under all variations in the external circuit; and as such a machine does not at present exist, it becomes necessary to employ somewhat unsatisfactory hand regulating devices. Difficulties also arise with regard to the regulation in the secondary circuit.

The E.M.F. appearing in the secondary circuit varies directly with the strength of the primary current. It also depends upon the number of convolutions in the two coils, and the goodness of the magnetic circuit (that is, upon the mutual induction between the two coils), and also upon the rate of alternation; but as these quantities are usually fixed for any given transformer, we may say that the secondary E.M.F. varies simply with the current passing through the primary. The strength of the secondary current, however, will depend largely upon the resistance of the secondary circuit. Now in the case of a series transformer the primary current is kept constant, therefore the secondary E.M.F. is also constant, and manifestly we cannot maintain a constant potential difference at the secondary terminals, nor a constant secondary current, if the secondary resistance is in any way varied. Were the lamps joined up in parallel it would be necessary on cutting any one of them out to substitute an equal resistance, which would of course be wasteful.

The mutual induction might be, and in fact has been, varied to suit altering conditions by providing an adjustable core; but this is also unsatisfactory.

A better plan is to join either arc or low-resistance incandescent lamps in series, and on removing one to replace it by a resistance coil, or, preferably, by a choking coil, that is to say, by a coil of wire provided with an iron core, and having considerable self-induction. Its apparent resistance should be equal to that of the lamp which it replaces.

In such a series transformer the number of turns in the secondary is, as a rule, equal to that in the primary, through which a current of 10 amperes is maintained.

But if the transformers are joined up in parallel, and a constant (alternating) potential difference is maintained between the mains across which their primary coils are connected, then an almost constant potential difference can be obtained in the secondary circuit, even though the resistance therein be considerably varied. The lamps can be joined in parallel, and if the transformer is properly designed it will be almost self-regulating; for the current passing through the primary, and therefore also the secondary E.M.F., will be almost proportional to the number of lamps thrown in circuit, that is, inversely proportional to the secondary resistance.

The reactions which cause this self-regulation are very important and interesting, and in order to better understand them the student may, with advantage, again read some of the remarks concerning self-induction, &c., in Chapter VII.

On considering the construction of either of the parallel transformers just described, it will be apparent that since the primary coil consists of many convolutions, and is almost completely surrounded by a mass of soft iron, the conditions for enormous self-induction exist. In fact, supposing the secondary circuit for the moment to be absent, or disconnected, the self-induction is so great that an appreciable interval of time elapses, before a current in the primary rises to its full value, although the potential difference may be high. And if the potential difference be rapidly alternated, it will not remain constant in one direction long enough to allow any sensible current to be forced through the coil. But supposing the secondary circuit is completed through a rather low resistance, so that it is possible for fairly strong currents to flow therein, then the conditions are altered. For directly a current *commences* to flow in the primary coil, the lines of force springing out from the wire, not only cut the neighbouring convolutions of that coil tending to give the effect known as self-induction, but also cut, and set up an opposite current in the secondary. The lines of force due to this secondary current re-act on the primary coil (see fig. 116) in just the opposite sense to its own lines of force, tending thereby to neutralise the self-inductive effect, and allowing the primary current to rise rapidly. Although the length of the secondary is less than that of the primary, the current flowing through it is much greater, which may be expressed by saying that the lines of force per unit of length are more numerous. Consequently, if the secondary resistance is very low, allowing strong currents to flow, this reaction is competent to reduce the apparent primary self-induction to a very small value.

If then a number of lamps are joined in parallel in the secondary circuit, an increase in the number switched in means an increase in the secondary current, and a corresponding increase in its reaction on the primary, which allows a greater current strength to be attained therein. While when all the lamps are cut out, the primary self-induction is sufficient to throttle or choke back the current almost entirely. On account of these splendid self-regulating properties, nearly all distribution is performed by means of transformers joined in parallel. Although the size of the mains is somewhat larger than on the other system, the advantages far more than counterbalance this objection, and it is a comparatively easy matter to obtain an alternating generator which can maintain a constant potential.

By regarding the action of the primary upon the secondary coil in the manner developed in Chapter VII., it will be at once apparent that the currents in the two coils are always in opposite phase ; in fact, in an ordinary transformer, the secondary negative maximum occurs almost simultaneously with the primary positive maximum and *vice versâ*.

In all cases great care must be taken to avoid a leakage from the primary to the secondary circuit, for a potential difference of several thousand volts, such as is frequently employed, might cause a fatal accident in the actual lamp circuit should any other point in the primary circuit be making earth at the same time. Many safety devices have been suggested, one being the interposition of an earth-connected metal sheathing between the two coils ; so that any breakdown in the insulation would cause a sufficiently strong current to flow to earth, to melt a safety fuse in the primary, and thus disconnect that particular transformer without interfering with others working in parallel with it.

Such a fuse would also act if by any means the apparatus got short-circuited ; and something of the kind is essential, for otherwise not only would all the transformers be deprived of power, but the heavy current which would result might cause serious damage.

The metal sheathing referred to should be insulated with extreme care, and must not form a closed metallic circuit round the inner coil, otherwise powerful eddy currents would be induced in it.

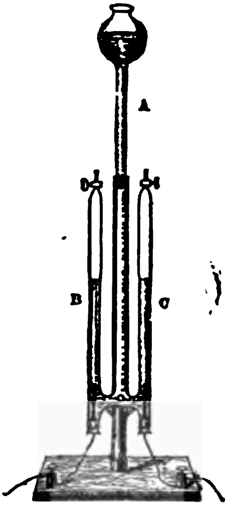
Another safety device is due to Major Cardew. Between two horizontal stout brass plates is placed a strip of aluminium foil, one end of which is free while the other is attached to the lower brass plate, which is in its turn connected to earth. The upper plate is connected to the secondary coil, so that should this plate assume a much higher potential than the earth, the foil would be raised by electrostatic attraction, and, touching the upper plate, would short-circuit the secondary coil. This would allow a sufficiently strong current to pass through the primary to melt a fuse placed in the circuit, and in that way cut out the transformer. If the primary circuit is making earth at any point, and any leakage occurs between the primary and the secondary, the upper brass plate is immediately raised to a sufficiently high potential to attract the foil, and cut out the transformer in the manner described.

CHAPTER XIV.

SECONDARY BATTERIES.

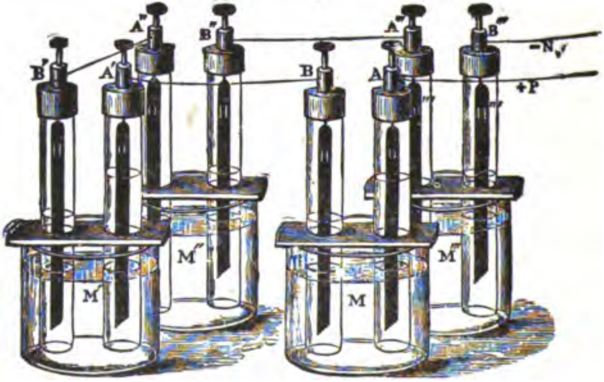
It was stated when describing the simple cell, that its great drawback, so far as concerned its general utility, was its comparatively rapid polarisation, a phenomenon which consisted in, or rather resulted from, the development of a film of hydrogen gas upon the surface of the negative plate. This hydrogen being electropositive to zinc, having, that is to say, a higher potential than zinc, a counter electro-motive force was set up, and the conditions for the flow of a counter current thereby determined. But chemical reactions, similar to those which take place inside a battery cell, may be repeated in any part of the circuit by causing the current to pass through suitably arranged metals and liquids. The usual method of performing electro-chemical experiments is to place the ends of the wires connected to the poles of the battery in a vessel containing the liquid upon which the current is to act. Thus, if the ends of two copper wires terminating in copper plates, are connected to the copper and zinc poles respectively of the battery, and placed in a vessel containing acidulated water, then the passage of a current will cause a quantity of that water to be decomposed, and the constituent gases, oxygen and hydrogen, to be released from their state of combination. The hydrogen will accumulate on the surface of the plate connected with the zinc pole, while the oxygen will combine with the other plate, just as it happened with the zinc plate in the simple cell. If, however, we substitute a strip of platinum for the copper plate connected with the copper pole of the battery, the liberated oxygen will not enter into any combination, but remain in a gaseous state, a large portion of it rising into the air, and the remainder adhering to the surface of the platinum or entering its pores and becoming in a measure occluded or absorbed by it. The absence of chemical combination between the platinum and oxygen is due to the weak chemical affinity subsisting between those two simple bodies. By observing proper precautions the two gases may be collected separately, the apparatus for the purpose of producing the decomposition and collecting the products being called a voltameter. Fig. 240 is an illustration of a serviceable form of this class of instrument. There are three glass tubes, all in communication at their lower extremities, the middle one, A, being taller than the others and terminating at the top in a small reservoir, to keep the two outer tubes, B C, supplied with solution, and to prevent the liquid overflowing when driven from B and C. Platinum wires are fused through the glass and terminate inside in strips of platinum foil, their outer extremities being connected to terminals fixed on the wooden base. Taps are ground into the upper portions of the tubes B, C, affording facilities for the escape, when required, of the confined gases. On sending a current through the solution, the decomposition of the water takes place, the oxygen collecting in one tube and the hydrogen in the other, according to the direction of the current. The graduations on the tubes show readily that the quantity of hydrogen evolved is always twice that of the oxygen, in consequence of the fact that the gases exist in that proportion when combined to form water.

Fig. 240.



If the platinum electrodes are now disconnected from the battery and joined up to a galvanometer, it will be seen that a current of electricity is produced by the voltameter, but that the direction of this counter or secondary current is opposite to that of the battery or primary current which caused the separation of the gases. A series of four voltameters constructed for this purpose, and known as Grove's gas battery, is shown in fig. 241. Each cell consists of two tubes, A B, closed at the top and dipping into a glass vessel, M. A platinum wire is fused into the upper portion of each tube, and carries a long strip of platinum foil. Assuming the current from the battery to enter the series by the wire P and leave by the wire N, oxygen will be collected on the electrodes O, O′, O″, and O‴, while hydrogen will be collected on H, H′, H″, and H‴. If, after the current has been allowed to flow for some little time, the terminals A and B‴ are connected to a galvanometer, a current will be observed to flow, opposite in direction to the charging or primary current, that is, from A through the galvanometer to B‴; and this reverse or *secondary* current, which is, after all, only the effect hitherto referred to as polarisation, taking place under favourable circumstances, will continue to flow so long as the gases remain in contact with the platinum. As a matter of fact, we have set up a secondary battery with 'plates' of hydrogen and oxygen, and in maintaining the current, the hydrogen in the tubes B combines with oxygen of the water forming new water molecules, while the equivalent hydrogen eventually released from the water combines with the oxygen in the tubes A. This action results, therefore, in the formation of water, as shown by the very simple equation :—

FIG. 241.



$$H_2+OH_2+O=OH_2+OH_2=2OH_2.$$

We see here, then, an exact counterpart of the action that takes place in a primary cell, resulting there in the polarisation of the cell and the tendency to generate so-called secondary currents.

The difference of potential or electro-motive force between the free hydrogen and oxygen is 1·47 volts, and that is a measure of the force of chemical combination between these gases, whence it follows that, in order to overcome this force of combination, and therefore to decompose the water, we must employ for each secondary cell a primary current whose electro-motive force exceeds 1·47 volts.

Cells in which the energy of chemical change can be thus stored up, to be given out again when required in the form of an electric current, are frequently called electrical accumulators or electrical storage cells. It is not, however, electricity which is stored or accumulated, but rather a quantity of the active constituents of a cell, and it is the subsequent chemical action between these constituents which causes the flow of electricity. It is therefore preferable to style them secondary cells. This will be more apparent when it is remembered that a primary cell can have a current sent through it in the opposite direction to that in which the current generated by it would flow, and this current will cause the usual negative plate to be more or less dissolved and the positive plate replenished, setting up the conditions necessary to the re-establishment of a primary current. If, for example, we suppose a powerful reverse current to be urged through a Daniell cell in which the copper sulphate has been exhausted, the copper plate will be partially dissolved and copper sulphate reformed, while zinc will be deposited upon what remains of the zinc plate. The cell is then able to again generate a current of its own.

Although the water cell is exceedingly interesting, as a secondary generator it is not a practical piece of apparatus, for it is only able to maintain a current for a very short space of time.

Many experiments have therefore been performed to determine the best liquid and electrodes (the metal plates immersed in the liquid), for a practical form of secondary battery. The most assiduous worker in this field was Plante, and the result of his labours was the discovery that lead electrodes in a solution of sulphuric acid give the best results. He found that a large portion of the oxygen combined with the plate at which it was released, forming an insoluble compound, which when opposed to a clean metallic lead plate developed a potential difference of from

2 to 2·½ volts. In Planté's method the lead plates employed were comparatively very large with a view to increasing the amount of active material and reducing as far as possible the resistance of the cell. They were first laid one over the other, but separated by strips of non-conducting material, and then rolled up together in a kind of double spiral. In this way an enormous surface was presented to the liquid. On sending a primary battery current through the cell, from plate to plate, the water was decomposed, the oxygen combining with the metal at the positive electrode to form peroxide of lead, PbO_2, while the hydrogen was precipitated upon the negative electrode in the gaseous form, without in any way attacking the metal. The cell so acted upon became a secondary cell in which the negative electrode acted as the positive plate, being a sheet of lead with a more or less complete film of gaseous hydrogen, the other plate or positive electrode with its film of insoluble lead peroxide behaving as the negative plate. It will thus be seen that the pole of the secondary which is connected to the positive pole of the primary generator, whether a battery or a dynamo machine, becomes the positive pole of the secondary, the other extremity becoming perforce the negative pole

On permitting the reverse or secondary current to flow, what remained of the hydrogen was oxidised and converted into water, some of the subjacent lead being also oxidised at the expense of the water. On the other hand, the peroxide on the other plate was deoxidised or reduced to metallic lead in a 'spongy' form. These experiments can be very easily performed by sending for a short time a current from three or four good-sized Daniell cells through a vessel containing two pieces of sheet lead immersed in sulphuric acid solution. The piece connected to the copper pole of the battery will, after the passage of the current, be discoloured, and assume a brownish tint, owing to the partial oxidation of the surface of the metal. The amount of chemical change taking place during these reactions is, however, very small, too small to answer any practical purpose, and this is due in a great measure to the comparatively small amount of surface exposed, and to the fact that the greater part of the hydrogen escapes instead of adhering to the plate.

The next step taken by Planté in the development of the modern form of secondary cell was an important one, and that was the adoption of a method for increasing the available surface of the metal electrodes. It was found that after sending the primary current through the secondary cell for some time, and so nearly covering the surface of the positive electrode with a film of the peroxide, the oxygen released from the water, instead of combining with the lead, formed into bubbles and escaped into the air. There was thus for a given metallic surface a limit to the amount of peroxide that could be formed.

The current was consequently reversed, that is to say, the cell was allowed to discharge itself almost completely, so that the spongy lead plate became oxidised, and the other deoxidised and reduced in its turn to the condition of spongy lead, with a proportionally increased surface. A fresh direct or charging current on being sent through the cell again oxidised this extended lead surface and reduced once more the negative surface to the spongy lead state. These reversing operations being continued for some time, both positive and negative surfaces were eventually very considerably increased and rendered more or less porous, one of them being always in a state of oxidation. After a few days, however, a period of rest was allowed between the reversals with a remarkable and most useful effect due to local action. The lead peroxide did not form a continuous impervious coating over the plate, but allowed the solution to pass between its particles and come into contact with the metallic lead. The peroxide being at places in direct contact with the lead, a simple voltaic pair was thus established with the lead for the positive and peroxide for the negative elements. The acid attacked the lead and formed lead sulphate ($PbSO_4$), which is, however, but a poor conductor of electricity; this sulphate became available for the subsequent electrolytic action. The amount of lead actually affected or made active was thus considerably increased and the porosity of the plate gradually made more and more complete. The process of 'forming' the plates might have been continued until the whole became porous by its conversion into spongy lead, but there is a practical limit to the action, for if pursued too far, the plate would fall to pieces simply on account of its inability to mechanically support itself.

The cell being once formed, no further reversal takes place excepting for the purpose of discharging it to perform useful work.

This method of forming the plate is, however, very tedious and very expensive, and many efforts have been made to overcome the objection. One method is to subject the lead to a nitro-sulphuric acid solution which rapidly eats into the metal and increases its surface correspondingly. Another method is to fill a vessel with molten lead, and, as it is on the point of solidification, to make an opening in the bottom, and allow such of the metal as remains in the liquid state to flow out, leaving behind it a spongy porous mass. This is cut up into plates of the required dimensions.

Lead plates pure and simple, often known as Planté plates, are now only occasionally used, the cell more generally employed being that based upon the idea of Faure, which was to coat the plates with a paste of lead oxide, and so to more easily extend the lead surface. A mixture of sulphuric acid and minium or red lead (Pb_3O_4) was made, which resulted in the formation of lead sulphate ($PbSO_4$). This was applied to both the positive and negative plates, that on the plate in connection with the positive pole of the primary battery being by the current converted into peroxide of lead, by the absorption of oxygen, while the paste on the other plate was reduced more or less to the condition of spongy lead. It will thus be seen that the great value of Faure's invention is to minimise the amount of energy required to be expended in 'forming' the plates.

It is now the practice to use a paste of litharge (PbO) and acid for the plate connected to the negative pole, although makers vary the pastes considerably. In some cases minium only is employed. In others a mixture of litharge and lead sulphate; and in others, again, all three substances, viz. minium, litharge, and lead sulphate enter into the constitution of the paste. In all cases, however, the ultimate result of the initial charging current is the same, viz. the conversion of the paste on the positive plate into peroxide, and of the paste on the negative plate into spongy lead. Assuming the plates to be in the state of lead sulphate and lead monoxide (or litharge) respectively, the initial action may be summarised by the equation :—

$$\underset{\text{Lead sulphate.}}{PbSO_4} + \underset{\text{Water.}}{2OH_2} + \underset{\text{Lead monoxide.}}{PbO} = \underset{\text{Lead peroxide.}}{PbO_2} + \underset{\text{Sulphuric acid.}}{SO_4H_2} + \underset{\text{Water.}}{OH_2} + \underset{\text{Lead}}{Pb}$$

It will be seen in this case that the positive plate exchanges its SO_4 for two atoms of oxygen, that the negative plate loses its oxygen, and that one of the water molecules is converted into sulphuric acid, so that the quantity of acid in the solution gradually increases, while the quantity of water as steadily diminishes.

The secondary current, during the process of discharge, reverses this state of affairs, the two plates being converted into lead sulphate. The process is doubtless brought about in several stages, but they may be represented by the following equations :—

$$PbO_2 + 2SO_4H_2 + Pb = PbO + SO_4H_2 + OH_2 + PbSO_4.$$

The lead monoxide then reacts with the sulphuric acid and forms lead sulphate and water thus :—

$$PbO + SO_4H_2 = PbSO_4 + OH_2.$$

Or combining the two equations :—

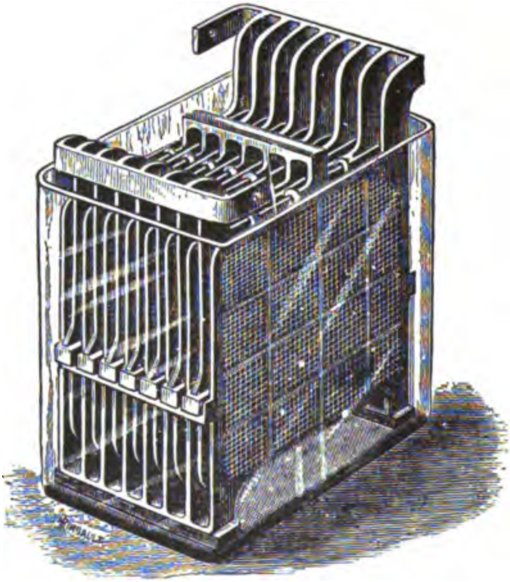
$$PbO_2 + 2SO_4H_2 + Pb = 2PbSO_4 + 2OH_2.$$

These reactions, however, affect only a small portion of the plates ; that is to say, the active portion of the cell is far less than that which remains passive.

The pastes, one and all, adhere very feebly to the lead plate, and many devices have been attempted to secure better adhesion. One of the earliest plans was to score or scratch the lead surface. Then it was indented, the indentations developing subsequently into perforations. The paste, on being squeezed into the holes, certainly kept its position much better than when simply smeared over the surface of the lead, but the quantity of paste exposed to the liquid was reduced. Eventually, leaden grids were cast containing sufficient metal to bear the weight of the plate, the holes being square and somewhat pyramidal, that is, smaller in the middle of the plate than on the surfaces, so as to prevent, as far as possible, the peroxide from falling out. An illustration of the latest type of cell, manufactured by the Electrical Power Storage Co., is given in fig. 242. A number of grids of lead, or of a hard lead alloy (lead mixed with a small proportion of antimony), are filled with the paste, the number varying with the size of the cell, but always with one negative plate in excess of the number of positive plates.

The cells are usually provided with 15 or 23 plates, of which 7 and 11 respectively are intended for the positive, and the remainder for the negative surface. The object of having a large number of plates, is, of course, to increase the capacity of the cell, and to reduce its internal resistance without resorting to the use of inconveniently large plates. Each grid measures about $8\frac{1}{2} \times 9\frac{1}{2}$ inches, and is $\frac{3}{16}$ inch thick, the weight being about 5 lbs.

FIG. 242.



The lead grids are provided with lugs for the purpose of connection, the lugs of the positive plates being all melted or cast on to one leaden strip or band, the lugs of the negative plates being similarly secured to another strip. The plates are placed in the cell alternately, the distance between two adjacent plates being about a quarter of an inch, which is sufficient to allow pieces of the plates or paste that may become detached to fall to the bottom of the cell. Bent strips or forks of ebonite, celluloid, or other suitable material are placed between the plates to keep them apart and prevent internal contact. The negative plates in each cell are also held rigidly together by means of two stout strips of lead melted on to solid extensions from the lower edges, two others being also secured to the sides of the plates about half-way up. These connecting strips, one of which is shown at the left-hand side of the figure, serve as a further means of keeping the negative plates in position. The bottom strips rest on slabs or strips of paraffined or varnished wood so as to support them at a height of about 1½ inch above the bottom of the containing cell, affording thereby plenty of room for any scales or pellets that may fall to the bottom to lie clear of the plates. Lugs cast on to the sides of the positive plates rest in small ebonite shoes, which are supported by the side-strips of lead attached to the negative plates. The positives are also connected together across the top by the substantial lead strip shown a little to the right of the middle of the upper edges of the plates. The connecting strip to be seen on the left is melted on to projections from the corners of the plates, consequently they can be readily lifted out of the cell, without necessitating the removal of the negative plates. The containing vessels are best made of stout glass, an opportunity being thus afforded for the proper inspection of the cell without taking it to pieces or removing the plates. The upper portion of the outer surface of the glass vessel should be coated with wax, vaseline, or some such material, to prevent 'creeping' and escape of the current by way of the moisture that would otherwise condense over the whole of the external surface. To further ensure good insulation, the cell should be placed on a varnished wooden tray or on two triangular pieces of wood supported by insulators of the so-called mushroom pattern illustrated in fig. 243. A sectional view of the insulator is also given in fig. 244. The channel in the lower cup contains a quantity of resin oil or of some other non-evaporating oil, in which the upper cup, coated with shellac varnish, rests. Sometimes, however, the cells are simply supported on shelving made of three or four strips of triangular wood. The cells should not be quite in contact, but tolerably close together, and the connections made by clamping the lead strips of adjacent cells firmly together—the positive pole of one cell to the negative of the next, and so on. The positive poles should be painted red for the purpose of distinction. All leading wires should be as short and of as low resistance as possible, so as to avoid unnecessary waste of energy in overcoming the resistance of the connections.

FIG. 243.

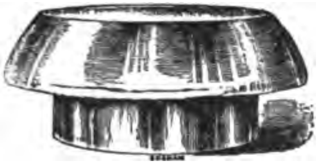


FIG. 244.

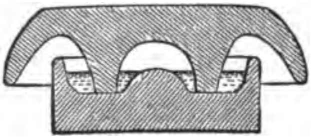
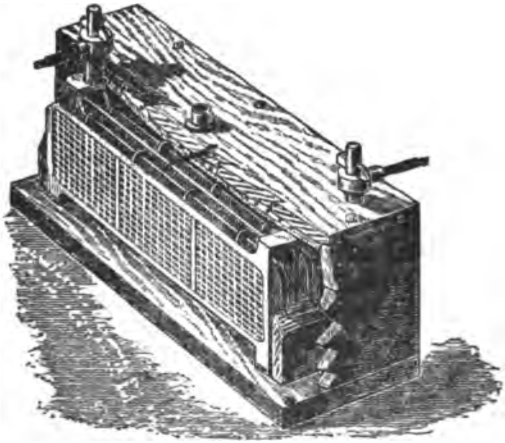


Fig. 245 illustrates a very useful form of cell specially constructed for train lighting. It is enclosed, like other classes of cells intended for ship lighting, carriage lighting, &c., in a teak box, and contains, to suit different requirements, either nine or fifteen plates separated by celluloid forks. Sometimes, in order to further avoid the risk of contact and short-circuiting between adjacent

FIG. 245.



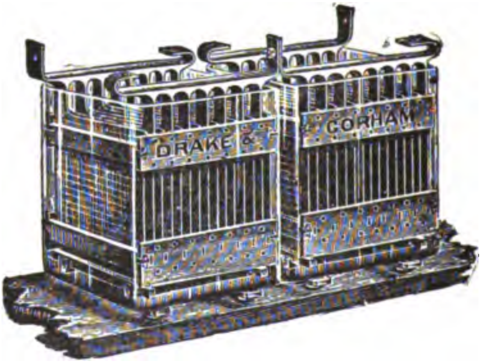
plates, thin perforated celluloid sheets are interposed between them. Connection between adjacent cells is of course made externally, rods attached to the connecting strips passing through the covers for the purpose. Connecting rings fit on to these rods, through slots in which wedges are driven to secure good electrical contact, the rings being joined together by stout wires or rods, as indicated in the figure. Cells are also made specially for tramcar driving, these being constructed as light as they practically can be, and enclosed in teak or ebonite boxes. They are made in four different sizes containing as many different numbers of plates.

A few details concerning some of these various types of cells will doubtless prove of service. In the subjoined table, L indicates cells intended for general, C for railway carriage, and T for tramcar lighting.

DESCRIPTION OF CELL		Acid 1·170 sp. g. for each Cell	WORKING RATE		CAPACITY	APPROXIMATE EXTERNAL DIMENSIONS				Weight of Cell complete with acid
No. of Plates	Material of Box		Charge Amperes	Discharge Amperes	Ampere-Hours	Length	Width	Height	Height over all	
		lbs.				ins.	ins.	ins.	ins.	lbs.
L 15	Teak .	35	25 to 30	1 to 30	330	9⅝	13	17⅛	19⅛	143
	Glass .	47	25 " 30	1 " 30	330	9¾	11¼	13¼	15⅜	128
L 23	Teak .	53	38 " 46	1 " 46	500	14⅜	13	17⅛	19⅛	228
	Glass .	67	38 " 46	1 " 46	500	14	11¼	13⅜	15⅜	211
C 9	Teak .	8·4	6 " 8	1 " 8	72	6	13⅝	6¼	7⅝	38
C 15	Teak .	14	12 " 14	1 " 14	136	9⅝	13⅝	6¼	7⅝	62
T 15	Teak .	14	24 " 28	1 " 30	95	8¾	8¾	11⅛	13⅝	53
	Ebonite	14	24 " 28	1 " 30	95	8	7⅝	11	12⅝	42
T 23	Teak .	22	38 " 42	1 " 50	145	13¼	8¾	11⅛	13⅝	80
	Ebonite	22	38 " 42	1 " 50	145	12¼	7⅜	11	12⅝	66

Messrs. Elwell Parker also manufacture a very useful form of secondary cell, the main principles of which, however, are similar to those involved in the construction of the cell just described. Two of these cells are shown in fig. 246. The distinguishing features consist in the construction of the grids, and the method of supporting the plates. The grids are made of an alloy which is said to be considerably stronger than the material formerly employed, and to be practically inoxidisable in the sulphuric acid solution. The holes in the grids are 'burred' over, by a process patented by Messrs. Drake and Gorham, so as to form 'lips,' which assist in keeping the pellets of oxide in their places. The plates are ingeniously supported and kept in position by means of round projections which fit into parallel rows of holes perforated in slabs of ebonite, as shown in the figure. This is a detail, but it is a feature of some importance. In an earlier form of cell, the leaden pins were all in one line, so that should any conducting material fall into the cell it might drop across them and cause short-circuiting. To effectually prevent contact between adjacent plates, small ebonite 'forks' are placed between them, and the set of plates is supported on blocks of paraffined wood to keep them clear of the bottom of the cell.

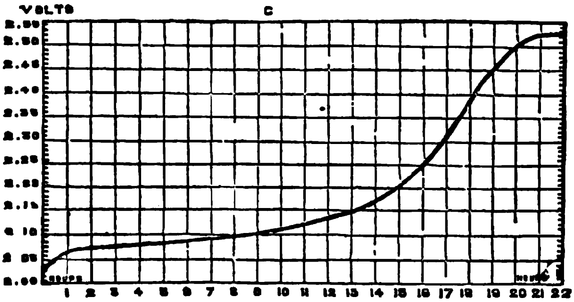
FIG. 246.



While it is essential that great care should be exercised in the manufacture of secondary cells, the treatment to which they are subjected is also a matter of great importance.

The charging current should be proportional to the number of plates, and, for the size of cell used for lighting purposes, should be equal to about 4 amperes per positive plate, so that the 15-plate cell requires 24 to 30 amperes. When the current exceeds this amount, it cannot increase the reduction of the sulphate of lead in proportion to the extra amount of current, and the surplus current is therefore wasted in the decomposition of water and the premature evolution of bubbles of oxygen gas from the positive surface, a phenomenon which is technically known as boiling. There is also a risk that the too-powerful current will cause bending or buckling of the plates, which, being very close together, stand a good chance of making contact one with the other, and so short-circuiting the cell. Precaution has also to be taken that the electro-motive force of the charging current should exceed that of the subsequent discharging current by about 10 per cent., or be at the rate of about 2·5 volts per cell, being, however, a little lower at starting than when approaching the completion of the charge. The charging should be continued until the solution assumes a milky appearance, consequent on the evolution of free oxygen, the positive plates having then absorbed as much of the gas as they can take up. The E.M.F. of a secondary cell rises, although not uniformly, with the continuance of the charging current. In some important experiments, performed by Messrs. Drake and Gorham with a battery of 15 cells, a current of 22 amperes was employed, by which the E.M.F. was raised from 2·02 to 2·53 volts per cell. The variations in the rate of increase are shown in fig. 247, from which it will be seen that after 220 ampere-hours had been put in, that is to say, after a charging current of 22 amperes had been maintained for a period of 10 hours, the E.M.F. had risen gradually to 2·13 volts. After about 14 hours charging, when the E.M.F. was 2·17 volts, a somewhat sudden rise in E.M.F. was observed, which was continued until 2·53 volts were registered. The maximum E.M.F. usually obtained is 2·5 volts, at which point gases are freely evolved, and cause the milky appearance already referred to as boiling. It was for some years

FIG. 247.



considered to be very injurious to charge the battery to an E.M.F. exceeding about 2·25 volts per cell, it being thought that charging beyond this point, or overcharging as it was called, was responsible for the remarkable tendency of the plates to buckle or twist out of shape, and so to loosen and detach the pellets. This, it was supposed, was brought about by the freed oxygen destroying the grid. It has, however, been conclusively proved that overcharging is not only harmless, but actually beneficial. In the experiments previously referred to, some cells were charged without cessation in order to ascertain the exact amount of current necessary to destroy the grid. It was soon evident that the process was, at any rate, a slow one; but the experiment was continued, until the full prescribed current had been passed through, for more than two months. At the end of that time it was found that the lead conductor was practically as sound as before charging. The coating of fine peroxide formed on the surface was very thin; there was no sign whatever of buckling, and, further, the specific gravity of the solution, when the cells were left in their then fully charged condition, remained absolutely unaltered. The conclusion thence drawn was that the oxidisation of the grid caused by charging only penetrated to a very limited depth, and then ceased entirely, and that the coating of fine peroxide formed, actually protected the grid not only from deterioration by overcharging, but also from local action, hitherto supposed to be unavoidable. It was, then, established that the life of the grids was not proportional to the amount of charging, *i.e.*, to the number of ampere-hours put into a cell. We shall return to this question presently, but it is necessary now to enlarge upon the precautions to be adopted in the process of charging.

The solution, prior to charging, should be put in the cells to the height of about ½ an inch above the negative plates. It should contain about 20 per cent. of pure sulphuric acid, and have a specific gravity of 1·170 (that is, if a given volume of water weighs say 1 pound, the weight of an equal volume of the solution should be 1·170 pounds); but it will be seen from the equations already given that some of the water in the cell is changed to sulphuric acid, and causes the proportion of the latter to rise to about 25 per cent., increasing the specific gravity to about 1·220. This accretion of sulphuric acid, which is, however, lost on recharging the cell, raises the conductivity of the liquid about 10 per cent.

An instrument for measuring the specific gravity of the acid solution becomes, therefore, a necessity. Such a piece of apparatus is called a hydrometer, or, for this special case, an acidometer, a useful form being that shown in fig. 248, which is simply a glass tube weighted at the bottom with a quantity of small shot. The lower the specific gravity of the solution, that is to say, the lighter it becomes bulk for bulk, the deeper will the hydrometer be immersed. As the liquid increases in density the instrument becomes relatively lighter and therefore rises. Consequently, the scale on the tube can be made to indicate the relative density corresponding with the various depths to which the tube descends. Another very useful form is that known as Hicks' hydrometer (fig. 249), which consists of a flattened glass tube with the upper end bent over so as to allow it to hang on the edge of the glass containing-vessel, the tube being also perforated to facilitate the free circulation of the solution. Inside the tube are four small glass globules containing liquids of different specific gravities and different colours; each globule rises or falls at a distinct specific gravity, and allows thereby the condition or relative density of the solution to be very readily observed.

FIG. 248.

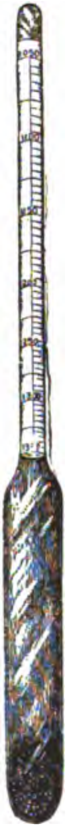
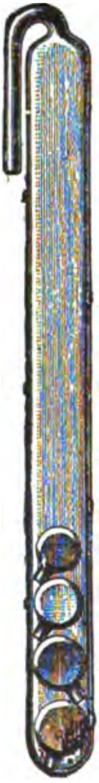


FIG. 249.

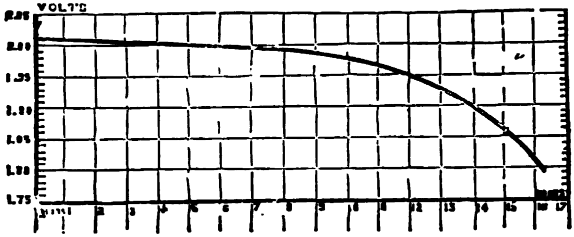


During the discharge the density of the solution falls until, when the cell is practically exhausted, it is only 1·150. The relative density of the solution thus affords an excellent means of ascertaining the condition of the cell.

The colour of the plates affords another good indication of their quality, the peroxidised positive plate being of a brownish or deep-reddish hue, and the negative or spongy lead plate being coloured grey or slate tint. There is thus a marked distinction in the colouration, which should always be discernible

During the discharge the E.M.F. of the cells speedily falls to about two volts each, the higher initial electro-motive force being, no doubt, mainly due to the presence of hydrogen on the spongy lead plate. When this has been oxidised there remains the lead surface between which and the peroxide plate the electro-motive force falls very slowly to about 1·98 volt. The fall is then slightly faster, although after an output of 400 ampere-hours at the rate of 25 amperes, the total drop from the time that the cell settles down to steady work at 2·02 volts, is only about ten per cent. The rate at which the fall of E.M.F. takes place is clearly shown in the instructive curve given in fig. 250, determined experimentally by Messrs. Drake and Gorham The discharge was continued, however, until the E.M.F. was only 1·80 volt per cell, which is a point about 0·1 lower than it is practically advisable to go. With a fall to 1·90 volt the difference is only about 5 per cent.

FIG. 250.



In an experiment performed to ascertain the effect upon the plates of a rapid discharge a battery was divided into two halves, one of which (A) was repeatedly run out, but the other (B) was never discharged beyond the point at which the E.M.F. commenced to drop. The experiment extended over a considerable time, but gave the instructive result that when exactly the same number of ampere-hours had been taken out of each half, the plates of (A) showed signs of expansion or growing, whereas in those of (B) no change could be detected. The life of the grid was therefore proved to be dependent not on the *amount* of ampere-hours taken out, or on the work done, but on the treatment of the plates.

By the time the E.M.F. has dropped to 1·90 volt the greater portion of the surfaces will have resumed the condition of lead sulphate ($PbSO_4$), and there will then be considerable risk of the formation of a more obdurate form of sulphate, Pb_2SO_5, caused probably by the $PbSO_4$ combining with the monoxide. This hard white sulphate is very troublesome. It is insoluble, non-conducting, and very adhesive. When it falls off the plate it generally carries with it some of the active material, which is therefore wasted. It is consequently highly important that the E.M.F. of the cells should be tested periodically with a special low-reading voltmeter. Two or three of these instruments were described in Chapter VI.

The experiments further showed that buckling was almost invariably accompanied by the formation of the hard sulphate on the face of the plates, and that this enamelling could be prevented by charging, and was not due to impurities in the oxides or acid used; further, that when the plates were free from sulphate there was no tendency to buckle. In the case of the first use of cells, when the acid was first put in, the specific gravity dropped in spite of the charging, indicating the formation of sulphate; by persevering in charging the sulphate disappeared, and with it the tendency to buckle. It is, therefore, evident, as already stated, that in order to avoid buckling of the peroxide plates, cells on their first use (whether new or after long disuse) should be charged incessantly until they are considerably overcharged.

It has been ascertained that in almost every case where abnormal disintegration takes place the plugs of active material fall out of the plates in complete halves and in very hard condition; and analysis has shown that they contain an excess of sulphate, due to insufficient charging. On the other hand, in a few instances the active material has been found to have become disintegrated and fallen off in a fine powder, and this was specially observable when on account of a leak in the containing-vessel and consequent frequent addition of water, the solution had become extremely weak

In this case practically no sulphate was present, and the mass simply lost cohesiveness.

It would seem, then, that a certain proportion of sulphate in the material is necessary to bind together, but that excess must be avoided.

Buckling appears to be due to the expansion of the paste during sulphating, for lead, being a very ductile but non-elastic body, does not re-assume its proper shape when the subsequent partial contraction of the paste takes place, and to this must also be attributed the loosening of the pellets. The contraction being but partial, the positive plates become gradually increased in size with continued use.

The electrolytic effect of the oxygen upon the lead grid, slow as it is, is to render it more or less brittle, whence the bars crack and split, and the plate is then practically worn out. Owing to the stretching effect of the paste, it is necessary that the grid should be of equal strength throughout, and not made stronger in one direction than in another.

Mr. Reckenzaun has found that a positive plate which had when new a surface of 90 square inches, grew to 94·76 inches after one year's daily use, while others showed when almost worn out an increase from 90 to 97 square inches; these measurements being simply the product of the length into the breadth of the plate, and independent of corroded or oxidised furrows. The actual amount of surface in contact with the liquid is considerably greater than these figures would indicate, owing to the irregularities produced by the solution. The life of a positive plate is not, however, so brief as might be anticipated from the many little difficulties which beset it, for with fair and continuous usage its period of durability amounts to about three years. The decay of the plate is more rapid in the lower than in the upper half, owing probably to the greater density of the acid solution in that portion of the cell. The life of a negative plate, which is subject to but few of the troubles attending the positive plate, has been estimated at ten years, although it remains for time to demonstrate the truth or otherwise of this calculation.

A 15-plate cell is capable of yielding a current ranging from 1 ampere or less to about 30 amperes, or at the maximum rate of

4 amperes per positive plate. The discharging current may be even a little higher than the maximum used in charging. It should not, however, exceed it by more than about 10 per cent., otherwise the subsequent efficiency of the cell will, as already shown, be seriously imperilled. Of course, the total output cannot exceed or even equal the amount of energy put in.

When the rate of discharge is too great, there is considerable risk of causing unequal expansion of the plates, resulting sooner or later in buckling, loosening of the pellets, and short-circuiting. It is impossible to prevent a certain amount of the obdurate sulphate forming, and this being an insulator reduces the available active surface and increases the resistance of the cell. As already indicated, considerable difficulty is experienced in removing this sulphate, and under any circumstances a certain amount of disintegration of the peroxide is sure to ensue.

But experiments have been performed which tend to show that with a considerable increase in the charging E.M.F. the sulphate can be decomposed. Its formation can be to some extent prevented, by the addition of a small percentage of sodium sulphate (Na_2SO_4).

If the cells are discharged and then left to stand idle for any length of time, the sulphating takes place rapidly, and causes premature buckling.

The capacity of a cell may be defined as the amount of energy it is capable of storing, and is calculated generally in ampere-hours, that is to say, it is the product of the number of amperes at which the cell is able to discharge, into the number of hours through which it can maintain that discharge. Capacity is also estimated by the ratio between the weight of the material and the electrical output. Thus the ordinary form of cells yields about four ampere-hours per pound of plates complete, while, it is said, the best form of Planté cells only yields about one-half as much. The amount of surface exposed to the solution really determines the charge which a cell can receive, and is therefore a measure of its capacity.

The capacity of a cell is an important consideration, seeing that the prime cost is considerable, that the cell is bulky and therefore requires correspondingly ample accommodation, and that at present only a portion of the plate is utilised. The capacity can be increased by more thoroughly 'forming' the paste and reducing the metal in the grid, which we may call so much dead weight, but it is not safe to carry this reduction much farther than has already been done, or there will be considerable risk of the plate being unable to bear its own weight, and therefore of its falling to pieces. It is, however, possible that some more active pair than spongy lead and lead peroxide may yet be discovered.

Many attempts have been made to use other electrodes than lead for secondary cells, but with little success. Thus one was brought out in which there was a lead plate to be peroxidised, the other plate consisting of copper to be alternately dissolved and deposited from a copper sulphate solution; but the low electromotive force of this cell precluded its adoption. For somewhat similar reasons the adoption of other suggested solutions has been found to be impracticable, and there is therefore no need to further discuss them here.

The most prominent of recent productions is that of Mr. Fitzgerald, who makes use of a solid block of peroxide for the positive plate, dispensing altogether with the grid. He calls this substance 'lithanode,' and cells containing it have been proved to have considerable capacity, exceeding 5 ampere-hours per pound of plates.

There is also the possibility that some improvement in the method of treatment may yet be discovered, and this is, apparently, not such a very remote possibility, seeing that three or four years ago, it was the unanimous opinion that overcharging should be carefully guarded against, whereas now it is a well-established fact that no harm can possibly arise from so doing, beyond a wasting of energy, while beneficial results frequently accrue.

Coming now to the question of 'efficiency,' or the ratio of the energy taken out of the cells as compared with that put into them, it may be repeated that the former can never equal the latter. The phenomenon of boiling, for example, is an evidence of energy being wasted, for the current is then employed in the unproductive decomposition of water. It is often asserted that secondary cells are capable of giving out 80 or more per cent. of the charging energy and this may be true with small cells wholly discharged, but the experience of those who have given the matter long and earnest attention is that the efficiency of cells of the ordinary sizes, discharged to their proper minimum E.M.F., ranges between 65 and 70 per cent. Even then great care has to be taken that the charging current is of the right strength and potential difference, and that the cells are maintained in the best possible condition. The efficiency of a cell depends very largely on the rate at which the energy is discharged, that is to say, it depends upon the current strength per unit of surface, or, as it is technically termed, upon the 'current-density.'

The highest safe rate, which has been already stated to be 4 amperes per positive plate, is equal to 0·01 ampere per square millimetre of surface, and an experiment with a small cell, quoted by Mr. W. H. Preece, shows how the efficiency varied with the rate of discharge or current-density thus :—

Current-density	Ampere-hours
0·013	44·6
0·048	30·5
0·090	30·2

It may be stated generally that the lower the density, the greater the efficiency, for with small cells slowly discharged, an efficiency or electrical return of upwards of 95 per cent. has been obtained. With a cell discharging at the rate of 5 amperes, an efficiency of 90 per cent. might be obtained, but on increasing the current to 40 amperes, the output falls to about 50 per cent., for when the rate of discharge is high, the E.M.F. is rapidly reduced. It is for this reason that with the 15-plate cell previously described, the discharge should not exceed 30 amperes, and if fully charged, such a battery can maintain this current for 10 hours, indicating a commercial capacity of 300 ampere-hours.

It remains now to consider the general utility and application of secondary cells. These features may be classed under three heads, viz. storage, regulation, and distribution.

As a means of storing energy to be afterwards converted into a current of electricity, the secondary battery stands alone. It is often compared to a domestic water cistern, but the analogy is not a very happy one, for the latter receives a periodical heavy charge of water to be delivered in small or large quantities as required, while the former frequently receives its charge gradually or even intermittently as opportunity arises, whereas its rate of discharge often approaches the highest possible, and frequently exceeds the charging rate, when, of course, the duration of the discharge is considerably shorter than that of the charge.

No better illustration of the value of secondary cells as a means of storing electrical energy can be afforded than that referred to by Mr. Preece in a lecture before the Society of Arts. He said: 'On March 30 my gas-engine broke down. I quite forgot to give notice to the makers to send down men to repair it until six days had elapsed. It took five more days to repair the engine, so that for eleven days I had not been able to re-charge the cells; but during all these days the light never failed, and we were not in any way inconvenienced. The useful capacity of my cells is 330 ampere-hours, and my nightly consumption is now about 30 ampere-hours. This was a very good test of the efficiency of the cells, for I obtained from them nearly all the energy they could usefully give. Only two cells were really exhausted during this time, but as I had two spare cells to replace them, their exhaustion did not cause me any inconvenience. The E.M.F. fell to 1·8 per cell, and the light in consequence was not so brilliant as usual. A good practical test of the efficiency of a battery like this is better than any isolated tests on single cells.' It will thus be seen that the use of a secondary battery reduces considerably the risk of a total stoppage resulting from the breakdown of the engine or other part of the machinery.

Secondary cells have also the advantage that, where they are used in sufficient numbers to maintain the ordinary number of lamps, they can, on emergency, be used to considerably increase the total amount of current supplied. For example, suppose the dynamo to be able to generate the same amount of current as the secondaries, the latter can be charged during the day, and both dynamo and battery employed independently for lighting purposes in the evening.

The battery is very useful as a regulator for maintaining a constant potential difference on a variable circuit which is being worked by a dynamo machine.

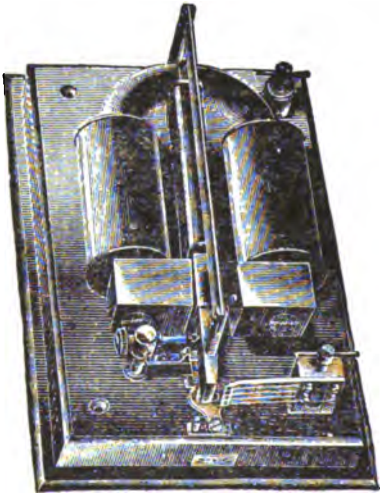
For such work, the battery is joined up across the terminals of the dynamo, which is constructed and driven so as to develop a slightly higher E.M.F. than the cells. Should the dynamo current, from any cause, fall in E.M.F. below that of the battery, an automatic switch cuts the dynamo out of circuit, and causes the circuit to be fed from the secondaries alone, with but little, if any, fall in the strength of the current. Conversely, should the dynamo E.M.F. become abnormally high, a comparatively strong current is urged through the cells, which form therefore a shunt to the main circuit and so keep the pressure practically uniform. Other applications of a somewhat similar character will be discussed when dealing with conductors.

There is another advantage pertaining to the use of secondary cells consequent on the fact that it frequently happens that the direct employment of an engine and dynamo for electric lighting purposes is inconvenient on account of noise, smell, &c. In such cases the current can be brought to the house by wire, and the energy there stored up for future use by means of secondary batteries, machinery of every kind being thus dispensed with.

The average electro-motive force of a secondary cell being two volts, and incandescent lamps, for the illumination of which they are mostly employed, being generally made to take a current with a potential difference of either 50 or 100 volts, it follows that, allowing a small margin for loss in the wires, switches, &c., 27 or 54 cells joined up in series will be required to maintain the necessary potential difference. The smaller battery of 27 cells would produce an electro-motive force of 54 volts, and assuming each cell to contain 15 plates and that the current strength is 28 amperes, the total output would be at the rate of $54 \times 28 = 1512$ watts, or, reckoning 746 watts to the horse-power, a trifle over two horse-power. A small portion of the electro-motive force would of course be absorbed in overcoming the resistance of the battery itself and its connections, the resistance of each cell during discharge being about 0·0012 ohm. The internal resistance, however, varies, as already stated, with the density of the solution and the condition of the plates.

An important piece of apparatus used in connection with secondary cells is the automatic switch, illustrated in fig. 251, which serves the function of automatically making and breaking the charging circuit at the correct moment, the circuit being closed soon after the E.M.F. of the dynamo exceeds the counter E.M.F. at the battery terminals by a predetermined amount, and broken as soon as the current falls to zero, the rupture of the circuit being accomplished without sparking. It consists of a horse-shoe electro-magnet fixed vertically and provided with large pole-pieces, approaching somewhat closely one to the other; a long central tongue oscillates between these pole-pieces, and has wound over it a coil of fine wire joined in parallel with similar fine wire coils on the outer legs of the magnet, and forming a shunt across the dynamo terminals. On starting the machine, the current passes through these coils, but when the E.M.F. rises to the required point, the tongue is attracted against the pull of a spiral spring, and, rubbing against the flat contact spring, closes the main circuit, which is completed through a few turns of thick wire on the limbs of the magnet, the direction of the current round the tongue and through the thick wire coils being such as to hold the tongue firmly over on the main-circuit spring. The thin-wire shunt coils round the magnet limbs are disconnected when the tongue is thus drawn over. On the cessation or failure of the main current, the spiral spring draws the tongue away from the main-circuit spring and, completing the shunt circuit, places the apparatus in readiness for charging immediately the E.M.F. rises to the required value.

FIG. 251.



Another useful piece of apparatus is an automatic alarum, the object of which is to indicate when an excessively high current is being drawn from the cells. In one of these alarums is a vertically fixed solenoid consisting of a few turns of thick wire, placed in the main circuit. When the current exceeds a certain prescribed limit, the soft iron core is attracted, and a horizontal spring attached to it completes a local circuit, causing one of the cells to send a current through an ordinary electric trembling bell.

In addition to these, there are many other pieces of apparatus, ingenious in their way, and useful for special purposes, which we need scarcely describe, although some of them will be referred to in the closing chapter.

CHAPTER XV.

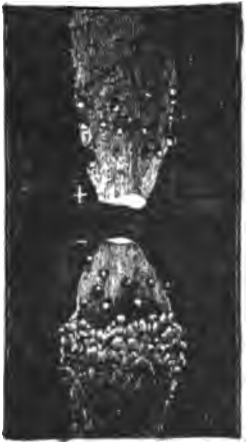
ARC LAMPS.

UNTIL within the last few years electric lighting was, except in the laboratory, only performed by the agency of the electric arc, a development of the classical experiment made by Davy in 1810, when he employed 2,000 primary cells of a very crude type, which he connected to two pieces of light wood charcoal about an inch long and one-sixth of an inch in diameter. When these 'were brought near each other, (within the thirtieth or fortieth part of an inch), a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness; and, by withdrawing the points from each other a constant discharge took place through the heated air in a space equal at least to four inches, producing a most brilliant ascending arch of light, broad and conical in form in the middle.' When any substance was introduced into the arc produced by this battery 'it became incandescent: platinum melted like wax in the flame of a candle; sapphire, magnesia, lime, and the most refractory substances were fused. Fragments of diamond and granite rapidly disappeared without undergoing any previous fusion.' The arched form taken by the luminous particles of carbon, resulted from the upward rush of the subjacent heated air. Were the carbons placed vertically, the particles would be disposed more symmetrically, and bear little or no resemblance to an arch. The term arch, in its abbreviated form, arc, is, however, retained as the name of the luminous space between the carbons.

The electric arc can be reproduced by placing in electrical contact two pieces of carbon, either of the gas-retort or of the prepared type, these forming the electrodes of a battery of twenty-five or more Grove or other cells of a similar E.M.F., and then drawing the carbons apart for a short distance. The electro-motive force of such a battery is altogether inadequate to cause a spark to dart across even the shortest air space. When, however, these rods are made to touch, a current is initiated, the particles in contact are immediately heated, and on separating the contact-surfaces, molecular disintegration and volatilisation take place and the air space is impregnated with so great a quantity of carbon particles raised by the current to a state of incandescence, that the resistance of the space is so far reduced as to allow the current to be maintained. The initiation of the arc is assisted by the momentary increase in the current due to self-induction in the circuit when the carbons are separated. The distance to which the carbons can be separated without absolutely disconnecting the circuit and so causing the arc to be broken, depends upon the E.M.F. of the battery, and can therefore, within certain limits, be increased by increasing the number of cells, or the potential difference at the dynamo terminals.

The maintenance of the ends of the carbon rods in a state of incandescence also involves a certain amount of consumption by ordinary combustion, some of the particles uniting chemically with the constituents of the atmosphere, although the products of combustion are very much smaller in quantity and far less harmful than those derived from a gas, oil, or candle flame. The two rods are not, however, consumed at equal rates, the consumption of the rod connected to the positive pole of the dynamo or battery, and called, therefore, the positive carbon, being approximately twice as much as that of the other or negative carbon; but this must not be taken as being invariably correct. One very interesting and important feature in connection with the electric arc is the difference of formation given to the carbon rods. The end of the positive rod becomes in a short time (see fig. 252) worn down to a somewhat conical form, the apex of the cone being, however, absent,

FIG. 252.



and the carbon hollowed out so as to form a kind of crater, and it is in the hollow of this crater that the most intense heat is developed, constituting it, therefore, the chief source of light. The negative rod is gradually consumed until its extremity is of a fairly true conical shape, but it is interesting to observe that some of the particles of which the positive rod is denuded are condensed upon the surface of the negative rod. When gas-retort carbon is used, the impurities fused give rise to small nodular growths which, under a lens or even a common magnifying glass, impart to the rods a remarkable appearance. These nodular excrescences do not manifest themselves when prepared carbons are employed. Their very presence denotes a wasteful consumption of energy, for they are, as it were, sorted out from the other constituents of the electrodes; they are then concentrated and liquefied, and urged across the arc from one carbon to the other, without emitting that percentage of light rays which would arise, were the energy they absorb expended on the carbon.

In consequence of the unequal consumption and the remarkable difference in the ultimate formation of the extremities of the carbon rods, much of the light is really lost: more especially is this so when, the carbons being placed vertically one over the other, the light is required in a horizontal direction on one side of the lamp. This loss can be partially avoided by placing the lower carbon a little out of line with the upper one, so that, instead of a crater being produced at the end of the upper or positive rod, the carbon is burned away in a more or less perfect curve on one side of the rod, the incandescent surface behaving to some extent as a reflector and projecting the light in a horizontal plane.

In some experiments performed at the South Foreland, it was found that, the intensity of luminosity in a horizontal direction from an arc established between two carbons placed vertically one over the other being taken at 100, the relative intensity when the lower end of the upper carbon was placed just behind the upper end of the lower one was—

In front . . .	287	or	2·87	times	as strong.
On one side . .	116	„	1·16	„	„
On the other side .	116	„	1·16	„	„
Behind . . .	38	„	0·38	„	„

Of course, this disposition of the carbons is only of service when the light is required to be concentrated on one side of the lamp.

In some instances the light is maintained by an alternating current, and under such circumstances the 'crater and cone' formation of the carbons does not result, both carbons being more or less pointed, and consumed at equal rates. A lamp fed by such a current does not, therefore, direct so many of the light-rays downwards, as compared with a direct current lamp, but diffuses them more uniformly in all directions. For ordinary purposes the direct current lamps are to be preferred, for it rarely happens that the light is required to be directed upwards or even horizontally.

It is very difficult to ascertain the temperature of the electric arc, and it has been variously estimated. The positive carbon is probably heated to a temperature somewhere between 2,400° and 3,900° C., and the negative to between 2,100° and 2,500° C.

The phenomenon which we have referred to as molecular disintegration, and which is one of the distinctive features of the electric arc, may perhaps be more correctly described as a case of actual volatilisation. So far, it has been impossible, by any other means of heating available, to convert carbon into the liquid, much less into the gaseous condition. Were it possible to volatilise this highly refractory material, a knowledge of the temperature at which the conversion takes place would be useful in determining the actual temperature of the arc. It is, however, a matter of common knowledge that all bodies on being raised to the same degree of temperature become equally luminous, and that a given luminosity results from, or is dependent upon, a definite temperature. It follows from this, that if on different occasions, a carbon rod were raised to the same luminosity, it would be at the same temperature, and, *vice versâ*, if it were raised to the same temperature on different occasions, the light emitted in each case would be of the same intensity.

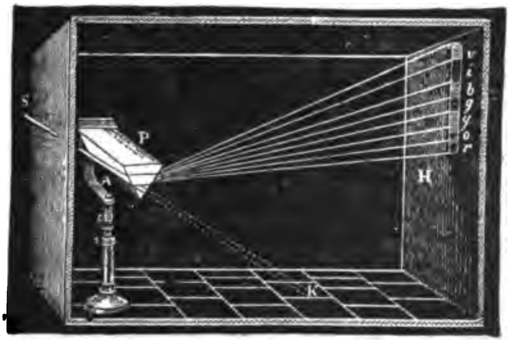
For the sake of those of our readers who are not acquainted with the character of a beam of light, a few words on the subject may not be out of place. Pure white light is in reality composed of rays of seven different colours superposed upon one another, or blended together. These colours are red, orange, yellow, green, blue, indigo, and violet, and it is by the simultaneous reception of these rays, in certain definite proportions, by the optic nerves, that the sensation of white light is conveyed to the brain. The generally accepted theory which endeavours to explain the manner in which a beam of light is propagated, is based on the assumption that all interstellar space, and likewise the space between the minute particles of all material bodies, is pervaded by that mysterious medium already referred to as ether.

A body may be said to be a luminous substance when it is a source of light-rays, such as the sun or a candle flame. Now the luminosity of a body is ascribed to an almost infinitely rapid vibration of its molecules; this vibratory motion is communicated to the ether particles pervading and enveloping the substance, and is propagated in all directions in the form of spherical wave-motions. The colour of the ray varies with or is determined by the rate of vibration. The velocity with which light travels is about 186,000 miles per second, and it has been calculated that the length of a wave of the extreme red end of the spectrum (that is to say, of a luminous ray having the lowest rate of vibration), is such that 39,000 such waves, placed end to end, would cover only one inch, while 64,631 of the extreme violet waves would be required to span the same distance. It follows that in one second, 464 millions of millions of red waves, and 678 millions of millions of violet waves, enter the eye and strike the optic nerves.

If a beam of solar light (S, fig. 253) is allowed to pass through a hole in the shutter or wall of an otherwise absolutely dark room, it will illuminate a small section of the floor, K, but if a prism or wedge-shaped piece of glass (P) is placed in the track of the beam of light, after the manner shown in the diagram, the beam will be diverted and the rays separated; on emerging and being allowed to fall upon the screen, H, or even on the wall of the room, it will be found to consist of the seven colours above enumerated. This many-coloured band of light is generally referred to as the spectrum.

If the beam is not of a pure white colour, the impurity or irregularity may be due to the chemical constitution of the source

FIG. 253.



of light, or to varying degrees of luminosity. For example, if a beam from a red-hot substance is allowed to fall upon the prism, the decomposition or separation of the rays will not result in the formation of the seven coloured bands, those near the violet end of the spectrum being absent on account of the vibrations being insufficiently rapid to produce them. When a source of light is heated to different degrees of luminosity, the spectra resulting therefrom will consequently vary, while, on the other hand, if it is raised at different times to the same temperature, and therefore to the same degree of luminosity, the spectra obtained will be identically the same in each case. Now it has been ascertained that the spectra of the white light emitted by the incandescent crater of the positive carbon are always identically the same, that in fact the same proportion between the various coloured bands is always evidenced, whence it is at once deduced that the temperature of that portion of the arc is always raised to the same point. This constitutes one great reason for accepting the proposition that the transference of carbon particles from the positive to the negative rod, is caused by a volatilisation at the former and a resolidification at the latter; for, so far as experiment has hitherto led us, there is for a given material, a constant critical point of temperature at which a change from the solid to liquid or to the gaseous state ensues, and, the most important point of all, this temperature is not any further increased until the whole of the solid body has been so changed. It will be evident that the admixture with the carbon of any foreign body (all such bodies having a lower critical point of temperature than carbon), must lower the temperature at which volatilisation ensues, and therefore reduce the luminosity of the crater. Moreover, when a body is transformed from the solid to the liquid or gaseous state, a certain amount of heat, known as the latent heat, is absorbed in the process. Thus one pound of ice at the freezing temperature absorbs about as much heat during its conversion into water at the same temperature, as would suffice to raise the same mass of water from the freezing temperature to 80° C.; whence the latent heat of water is said to be 80° C. On the other hand, when a liquid is solidified a corresponding amount of heat is given out during the change. Thus one pound of water at the freezing temperature in being converted into ice, gives out as much heat as would raise the temperature of the same mass to 80° C. Returning then to the electric arc, if the positive carbon is more or less volatilised, a certain quantity of heat is absorbed in bringing about the change, whence, on the carbon being resolidified on the negative rod, a corresponding quantity of heat is evolved.

These reactions have been made to account for a very remarkable phenomenon pertaining to the electric arc. It has been found that when the arc is established a back or counter E.M.F. is set up amounting to nearly 39 volts. This effect is somewhat analogous to that, accounting for the reaction which is set up when a current is sent through a voltameter, and which was fully entered into in the preceding chapter. The effect is also parallel to that remarkable feature in the action of electric motors, viz., the counter E.M.F. which is set up by the armature when it is caused to revolve in an established electro-magnetic field. In fact, the phenomenon affords a new demonstration of the law that every action brought about by any force, sets up a reaction or counter-force.

The theory of the existence of this counter E.M.F. does not, however, depend solely upon the assumed volatilisation and re-solidification of the carbon particles. It is a matter of general knowledge, and one which has given rise to many different conjectures, that the *apparent* resistance of the arc does not increase proportionally with the distance between the rods. The resistance of an arc of one-tenth of an inch appears, in fact, to be nothing like double that of an arc of one-twentieth of an inch. If, however, the resistance of the air space with its impregnation of carbon particles, were the only element entering into the question, the resistances in these two cases should be exactly as two to one. Now, experiments have been made with arcs of different lengths (the electro-motive force being also varied so as to keep the current strength constant), with the result that, allowing for a definite counter E.M.F. of 39 volts, there remained a resistance which, as we should expect, varied proportionally with the length of the arc, and affording thereby a demonstration of the actual existence of the counter E.M.F.

The great practical lesson to be derived from a knowledge of this effect is that the E.M.F. of the current which is passed through the lamp must always exceed 39 volts, or it will fail to maintain the arc, in just the same manner that an E.M.F. exceeding 1·47 volts must be employed to decompose water. It is in fact usual to provide an E.M.F. of between 44 and 50 volts for each lamp, the actual or net resistance of the arc itself, that is, of the air space separating the carbons when they are in the normal position for lighting, or at a distance of about 3 millimetres apart, being variously estimated at something between one-eighth and one-half of an ohm.

The resistance of prepared compressed carbon varies with the different makers, the resistance of one specimen amounting to 2,430 times that of a similar piece of pure copper, or nearly 4,000 microhms per cubic centimetre. The specific resistance of the comparatively impure and more crystalline gas-retort carbon has been shown to be about 17 times as great as that of the prepared material. The actual resistance of the prepared carbons ordinarily used for arc lamps is about 0·15 ohm per foot. In order to reduce this they are frequently coated with a very thin layer of copper deposited electrolytically. But great care must be taken that the metallic deposit is very thin, otherwise it will melt for some distance up the rod, and there will be a danger of fused globules falling off on to the glass globe and fracturing it. It may also be in sufficient quantity to decidedly tinge the flame of the arc with the characteristic green hue of burning copper.

The composition and method of preparing or manufacturing artificial carbons varies considerably, the precise details being in most cases regarded as trade secrets. Generally, however, finely pulverised coke forms the basis, this being intimately mixed with pure carbon powder derived from the destructive distillation of some such organic substances as gas-tar, pitch or bitumen. An adhesive substance, such as a syrup of cane sugar and gum, is then added to make a paste, the rods being shaped by forcing the mixture with considerable pressure through a die plate. The rods so formed are then baked in an oven a number of times, to decompose the carbonaceous compounds, and drive off the volatile constituents. Immersion in syrup usually takes place between the bakings. But great care is taken to remove any foreign substance from the ingredients, and so to ensure the production of a homogeneous rod, for, as will have been already gathered, the presence of foreign bodies in the arc causes fluctuations in its luminosity, and considerable variations in its colour.

The chief requirements which it is necessary that a carbon rod should fulfil are then, that it should be dense, that its molecular or mechanical structure should be uniform, that it should be pure, and that its electrical resistance should be low. The diameter of the rod varies with the light it is required to give or the current it is required to carry, those most frequently employed ranging from 7 to 10 millimetres in thickness, and these give an actual luminosity of about 875 candle-power per $\frac{2}{3}$ horse-power absorbed, and approximately this may be taken as the power required and the actual amount of light emitted by an ordinary arc lamp. The usual practice of referring to the light of such a lamp as being of 2,000 or more *nominal* candle-power is, therefore, very misleading. The use of globes still further reduces the actual amount of light obtained from the lamp.

The proportion of light cut off by globes has been determined to be :—

For clear glass . . .	about 10	per cent.
„ light ground glass . .	„ 30	„
„ heavy „ „ . .	45 to 50	„
„ strong opal „ . .	50 to 60	„

Assuming an arc lamp to give a light of 875 candle-power when the current strength is 10 amperes and the E.M.F. 50 volts it will be evident that this amount of light is produced at a cost of 500 watts, so that were a lamp to consume one electrical horse-power or 746 watts, it should yield a light of about 1,300 candle-power. Allowing for the various losses in the conversions, it may be taken that on an average arc circuit, the engine indicates one horse-power for each ordinary or 875 candle-power lamp.

The Jablochkoff 'candle,' which was devised by M. Paul Jablochkoff in 1872, and which caused considerable excitement at the Paris Exhibition of 1878, is undoubtedly the simplest form of arc lamp yet introduced. although, as it is not economical, it is used less extensively than it otherwise would be. The candle consists of two pencils of prepared carbon about 22 centimetres long and 4 millimetres in diameter, fixed parallel to one another but separated by a strip 2 millimetres thick, of some fusible non-conducting material such as kaolin. Pieces of split brass tubing. 5 centimetres long, are placed over the lower ends of the carbon pencils and serve to form connection with the holder which is attached to the base of the lamp. The upper ends of the pencils are scarfed, and a small lighting fuse consisting of a paste of plumbago and gum serves to connect them together electrically and affords a path for the initial flow of the current. This fuse is speedily consumed and the arc established. The consumption of the positive, as compared with the negative carbon being with a direct current approximately as 2 : 1, an alternating current is employed, so that the pencils are uniformly consumed, the insulating material also being burnt at the same rate. Each candle lasts about an hour and a half, and owing to the interposition of the insulating strip, that is, to the separation of the carbons, a candle after having been once extinguished cannot be re-ignited unless a fresh lighting fuse is added, or the pencils temporarily connected by a piece of wire, or another piece of carbon.

The lamps are joined in series on a circuit through which a current of eight amperes is sent, the potential difference necessary at the terminals of each lamp being about 42 volts. The rate of consumption of electrical energy is therefore about 336 watts, and this is sufficient to yield, from an open light, a luminosity of 400 actual candle-power.

It is customary to fix a number of candles, generally four, in a lamp, and consume them in succession. In this way, the light can be maintained for six hours without any attention being given beyond that of turning a switch, so as to divert the current from one candle to another. The form of candle-holder most frequently employed consists of two short rigidly fixed pillars, one of them being slotted so as to allow a small play for a triangular piece carrying the socket for one of the carbons, the other socket being cut in the other pillar A stiff flat spring presses against the free corner of the triangular piece, which can be moved to and fro in the pillar. On pressing the candle in between these pillars, a good mechanical support, as well as good electrical contact, is afforded.

There are two kinds of lamp bracket for supporting the holders. In one of them, one pillar of each of the holders is electrically connected to a common terminal, the other pillars being connected each to a separate terminal, so that at least five leads are necessary. In the other type each candle has a separate holder, each holder requiring two terminals and a distinct pair of leads from the switch.

Sometimes a switch is placed on or near each lamp, but it is more general to divide the lamps into a number of separate circuits, each circuit comprising four lamps joined together in series and manipulated by a single switch placed in the dynamo-room.

An automatic arrangement is also employed to avoid the risk of burning the candles right down to the sockets and so causing a disconnection. The apparatus consists of a vertical solenoid with a core which is provided with two pairs of contacts. Should the circuit be broken by one of the candles 'going out,' the core falls and two of the contact points fall into mercury cups and complete the circuit of an electric bell. At the same time the other pair of contacts drop into mercury cups which complete the circuit through the second series of lamps The attendant has then only to shift the leading wire to the terminal block of the next circuit in readiness for his next act of negligence.

The Jablochkoff system has very few advocates in England, chiefly on account of its cost, but it is a very simple system and one which finds great favour in such places as the Indian palaces, where money is not scarce, and where skilled labour is practically unprocurable. Other forms of electric candle have been devised, but as they are all now extinct, we need not pause to consider them.

Another class of arc lamp, frequently called the semi-incandescent, used, however, with a direct current, is typified by the Werdemann lamp, which consists of a large rounded block of carbon connected to the negative lead and supported by a hinged bracket. The positive lead is connected to a thin pointed carbon rod, and, by means of a weight attached to a cord working over a pulley and fastened to its lowered end, this thin rod is kept in contact with the hinged block. Both carbons become incandescent at, or in the vicinity of the point of contact, and a small circular arc is struck. The rod is of course somewhat rapidly consumed, and a hole gradually formed in the carbon block. Great things were expected of this lamp, but it did not prove economical; it was very variable, flickered considerably, and is now practically obsolete.

Our chief object in referring to these lamps, was to give some little idea of the channels into which men's minds were directed in their earlier efforts to 'subdivide' the electric light, or more correctly speaking, to maintain a number of comparatively small lamps on one circuit.

Coming now to the question of arc lamps in their present state, it would be convenient if we were able to classify them, or divide them into a few distinctive types, but there is absolutely no simple or natural classification, and a complicated or forced division would be undesirable.

Many efforts have been made to obtain a precise but comprehensive classification, with the result that there are virtually as many classes as there are lamps. It would be possible to divide the lamps into two classes, viz., those used in series, or on a circuit through which a *constant current* is sent, and those used in parallel, or which have a *constant potential difference* maintained at their terminals. The latter kind are comparatively simple, but any lamp of that class could be transferred to the other by an alteration in the winding of the coils and by the addition of a 'cut-out' device, to automatically short-circuit the lamp, in the event of a disconnection in the arc-circuit.

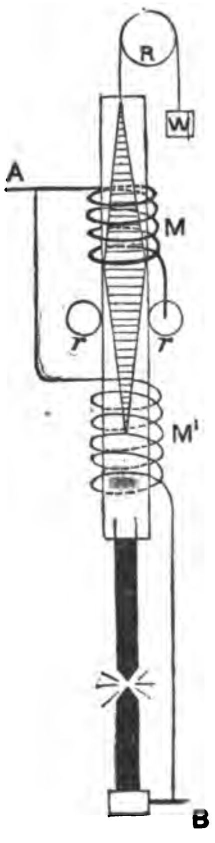
This system of classification, therefore, can scarcely be said to be satisfactory. It is, however, an important feature that the series system is characteristic of the arc lamp, owing to the fact that the main leads need only be small as compared with those necessary for parallel working. With the small current usual on a series circuit, the loss due to the resistance of the leads is trifling as compared with the loss that would be experienced were the same leads used for parallel lamps. For this reason parallel arc lamps are not often used, although they have the advantage that they can be so adjusted as to render it possible to join them in parallel with incandescent lamps. In all cases it is essential that the lamp should automatically 'strike' its own arc, or cause the carbons, when in contact, to separate to the required distance; and this action must perforce be controlled by the main current, that is to say, the separation of the carbons must always be brought about electrically, and the coil used for the purpose must always be placed in the main circuit. This coil is usually referred to either as the main, or the series coil, the latter term being employed because the coil is joined in series with the carbons. When lamps are joined up in parallel, a small resistance coil is placed in series with each lamp for steadying purposes. Without this resistance, a slight variation in the length and resistance of the arc, or the reduction in the resistance of the carbons as they burn away, would cause a sensible variation in the current strength; but the use of a resistance coil reduces the percentage of the variation in the resistance of the particular branch, and therefore keeps the current strength more nearly uniform. To compensate for the loss of power in the 'steadying' resistance, the E.M.F. provided is about 5 volts higher than that provided per lamp when joined in series. With lamps joined in series this extra resistance is unnecessary, because when the resistance of any one lamp varies, the current strength is not appreciably affected; the other lamps in circuit with it, in effect, act as a steadying resistance, and tend to keep the current strength constant.

If the source of light is for focussing purposes required to remain stationary, which is, for lighthouse or lantern work, of paramount importance, both carbons must be automatically movable, at their respective rates of consumption; but when this is not absolutely necessary, as, for example, in ordinary street or shop lighting, then it is only necessary that one carbon should be fed forward towards the other, which is supported in a fixed socket, and which gradually burns away. The latter form of lamp is, as a rule, simpler in construction and correspondingly cheaper than the former, or 'focussing,' type, but in this case, too, classification is out of the question, as the one form can be easily converted into the other.

It might also be possible to divide lamps into alternating and continuous current lamps, but this classification would be unsatisfactory, for little if any fundamental difference in the principles of construction are involved. One point may, however, here be mentioned, and that is, that with lamps used on alternating-current circuits, it is necessary that the cores of the electro-magnets should be short and laminated in order to minimise self-induction and eddy currents, and so enable them to respond quickly to the reversals.

We should like to divide lamps into two classes, viz., those in which the 'feeding' forward of one or both of the carbons is controlled mechanically, and those in which the controlling agent is electricity alone. But we are here met with another difficulty, for even those in which mechanism is employed for feeding, require the intervention of the current to release or start that mechanism. The simplest 'mechanical' lamp would be one in which the upper carbon feeds downwards by gravitation, that is, in virtue of its own weight, when the current passing through the coil used for striking and maintaining the arc is incompetent to overcome this force of gravitation ; and we shall see, in the Gulcher lamp, that this degree of simplicity is in great measure approximated to. The Gulcher is, however, a parallel lamp, and the principle is only applicable to such. When the lamp is used on a series circuit it is necessary to provide a second coil, which, by acting in opposition to the striking or series coil, feeds the carbons forward when the length of the arc becomes too great. This second solenoid is joined across the lamp terminals, forming a shunt to the series coil and the arc. The striking or series coil placed in the main circuit is of low resistance, while the feeding or shunt coil is of high resistance, the proportion of the resistances being usually about 1 : 100. As these coils have antagonistic effects, the lamps may be called 'differential.' It will, however, be observed that some of these so-called electrically controlled lamps involve delicate mechanical contrivances. To be purely electrical, the moving carbons would require to be perfectly balanced and only movable under the preponderance of the effect of one coil over that of the other. But no such lamp is now in practical use, so that for this and other specified reasons the division into mechanical and electrical control falls to the ground. The nearest approach to an electrically controlled series lamp is the Pilsen, the only deviation from the principle being the addition of a small weight to the upper carbon holder.

FIG. 254.



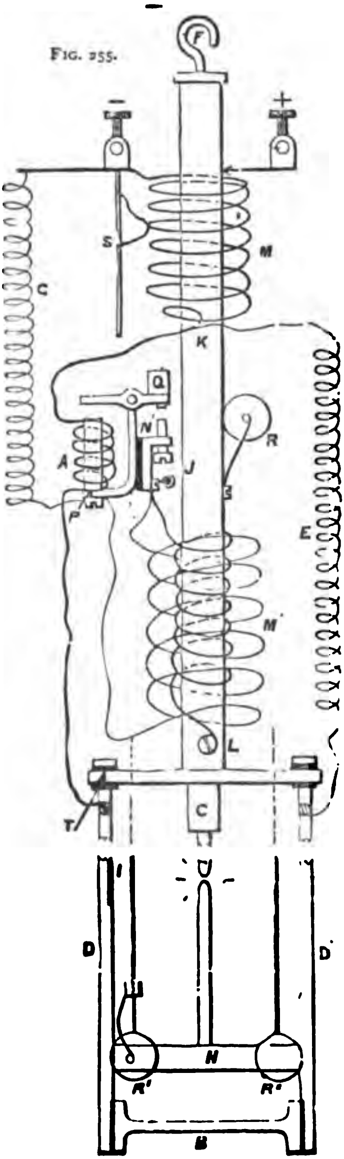
The fundamental principle upon which the differential arc lamp is constructed, is clearly indicated in fig. 254. The current on arriving at A is divided between the two paths, one of low resistance, and the other of comparatively high resistance. The former, or main circuit, includes the thick wire coil M, from which the current passes to the contact guide roller *r*, and from thence through the frame to the upper or positive carbon holder, the circuit to B being completed through the arc and lower carbon holder. The other, or shunt, circuit consists of the coil M^1, which comprises many turns of fine wire, its ends being connected to A and B respectively. These coils are, in the lamp to which the diagram more particularly refers, wound upon a brass tube, inside which another brass tube is loosely fitted, so that it can slide up and down freely. The shape of the soft iron core is in this case like that of two long cones placed base to base; this core is fixed inside the inner tube, and is balanced by a weight W attached to a cord passing over the pulley wheel R.

The resistances of the coils M and M^1 are so adjusted that, the arc having been struck and having arrived at the proper length, the action of the coils upon the core is exactly balanced. Any increase in the resistance of the main or series circuit, caused by an increase of the length of the arc, disturbs this balance, increasing the current through the shunt coil, whence the core, with the upper carbon attached, is attracted downwards by the shunt coil, and in descending again restores the balance, readjusting the arc to its previous dimensions. It will thus be seen that in the event of a disconnection in the arc circuit such as might happen before lighting up, the coil M^1 takes the whole of the current, and continues to draw the core down until the two carbons enter into contact. Immediately this happens a heavy current passes through M at the expense of M^1, and the core and upper rod are raised just sufficiently to establish the arc. It may here be observed that were the core made of a simple cylindrical rod of iron, it would have a tendency to balance itself, or take up its position in the middle of the electro-magnetic field produced by the two coils; and although a variation in the magnetisation of either solenoid would move the core away from that position, it would manifest a tendency to return to it, and in so doing cause fluctuations in the arc. By using the conical core this difficulty is overcome, because as the magnetisation of the preponderating solenoid increases, and attracts the iron, it acts upon a gradually increasing core, so situated that it can never get into its 'best position,' but remains steady at any point in a comparatively long range.

Fig. 254, while serving to illustrate the general principle involved in differential lamps, is really a skeleton diagram of the Pilsen, (which was invented by Messrs. Piette and Krizik of Pilsen, a town in Bohemia,) and which, while simple in construction, works with remarkable steadiness, even under somewhat considerable fluctuations in the current. It has also the advantage that it is practically noiseless.

It has recently passed into the hands of the Gwynne-Pilsen Co., who have simplified some of its details and effected other structural improvements without, however. interfering with its fundamental principle.

FIG. 255.



A detailed diagram of the lamp is given in fig. 255. The coil-frame J and casing are electrically connected to the positive terminal +. From J the current is transmitted by contact rollers R to the inner brass tube C (containing the double conical iron core), and thus through the holder to the positive carbon. Thence it passes through the arc to the negative carbon holder H, and from thence through the contact rollers R' R'' to the negative guide rods D,' D^1, both of which are insulated from the bottom plate of the lamp, as well as from each other at B. The current being thus divided, one part (the lesser) passes through the iron wire coil E, and the greater part through the automatic cut-out coil A, these two branches reuniting at K, and thence passing through the main coil M to the negative terminal marked −, from which it is carried to the positive terminal of the next lamp in series, or the negative terminal of the dynamo, as the case maybe. The negative holder is supported by two cords which pass over pulley wheels and are connected to the brass tube containing the core. This is more clearly indicated in fig. 256, where the cords are shown connected to the rods attached to H, R R' being the pulley wheels.

One of these wheels, R′, has very fine teeth cut round it, into which the click, which is to be seen above the wheel, engages, so as to allow the wheel to rotate freely for feeding, but to prevent it moving in the reverse direction. The cord, therefore, during the separation of the carbons has to *slide* along the groove, sufficient friction being in that way introduced to prevent sudden or jerky separations.

Were the two holders exactly equal in weight they would counterbalance, but in the more recently constructed lamps, the positive holder is about 1½ ounce heavier than the negative, so that when no current is flowing the carbons run together.

The action of the series current then is to draw the iron core, to which the positive carbon is attached, up into the coil M, thus striking and maintaining the arc. In order to regulate the lamp, a shunt-current is taken from the screw L, and passed round a solenoid of stout copper wire, to the insulated bracket O, and returning from thence through the shunt-coil proper M^1, consisting of many turns of fine copper wire (wound in the same direction as the spiral of L), having its other end attached to the bracket P of the automatic cut-out, from whence it passes through a coil of stout German-silver wire G to the terminal marked —. The number of convolutions of the coil M^1 and their resistance are so proportioned that (when the arc has been drawn to a length of about ⅛ inch) the attractive action counterbalances that of the main coil M and the small extra weight of the positive holder. Equilibrium being thus established, the arc is maintained at its normal length and resistance, so long as the current is kept constant. If from any accidental cause (such as the fracture of a carbon, mechanical injury, or the breakage of a cord), the main current cannot flow from C to D and D^1; then the magnet A of the automatic cut-out fails to hold down its armature, which by reason of the weight on its unattracted end falls in the opposite direction, and establishes a contact with the screw N on the insulated bracket O, thus opening a path for the main current *via* L, O, N, Q, and G to the lamp terminal marked —. and so preventing a complete break of circuit or the destruction of the shunt-coil M^1.

The negative guide rod D^1, is fitted with a strip of ivory insulation I, so situated, that when the carbons are nearly burnt out, the contact roller R^1 ceases to make contact, the current ceases to flow round the magnet A, Q falls, and the lamp is cut out of circuit. The function of the alternative path from R$''$ through D^1 and of its iron resistance E is that when the lamp is burning, the resistance E causes the greater part of the current to pass *viâ* D, thus securing the efficient action of the magnet A, and preventing the lamp from becoming prematurely cut out. When owing to exhausted carbons the lamp is in process of cutting out naturally, the contact roller R^1 in passing from D on to the insulating strip I, would carry an arc after it from R^1 to D, were it not for the temporary path afforded from D^1 through E, until such time as the main current had been diverted through the path L, O, N, Q, G The German-silver coil, G, has no action upon the working of the lamp; it is a compact form of resistance, equivalent to the apparent resistance of the lamp, to be thrown into the main circuit, when the lamp is cut out automatically; it is superfluous with a self-regulating dynamo.

A view of the interior of the lamp is given in fig. 256, in which the lettering corresponds to that employed in the diagram, fig. 255. It will be observed that a means of final adjustment is provided by the movable contact S, which can be used to cut out one or more of the convolutions of the main coil M. The friction roller is here lettered *r*, and as already mentioned, R R$'$ represent the pulley-wheels over which the cords connecting the positive and negative holders together, are passed.

A sectional view of another form of the lamp is given in fig. 257, in which the two coils M and M^1 are wound on the same bobbin, but in opposite directions. The long conical core is clearly shown at D. The negative holder is suspended in the same way as in the bi-conical form, but the pulleys and other parts such as the cut-out are not shown in this figure. The lamp is also made with horizontal carbons, so as to render it suitable for rooms with low-pitched roofs, and it will be seen that the absence of mechanical control facilitates considerably the alteration in the design. It should be added that the workmanship of the Pilsen lamp is of the highest order; the finish is unusually good, and all pulleys, rods, and the working parts generally, are electroplated.

Another very simple and efficient lamp is that invented by Mr.

FIG. 256.

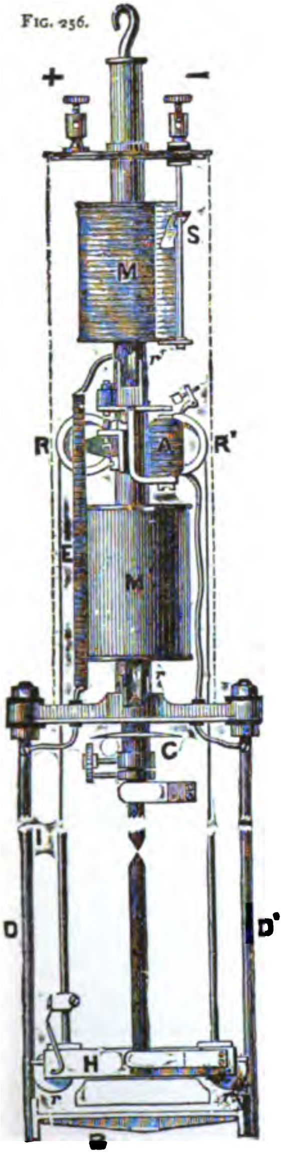
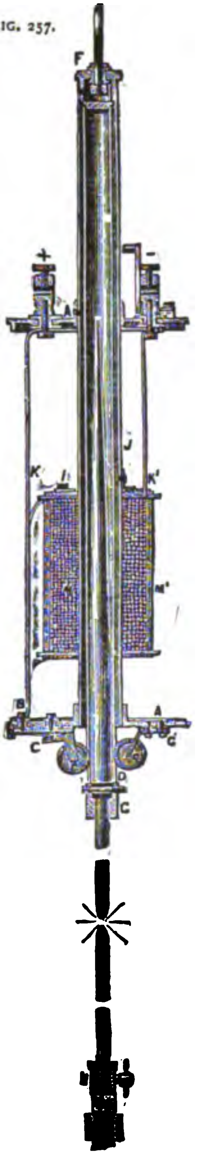
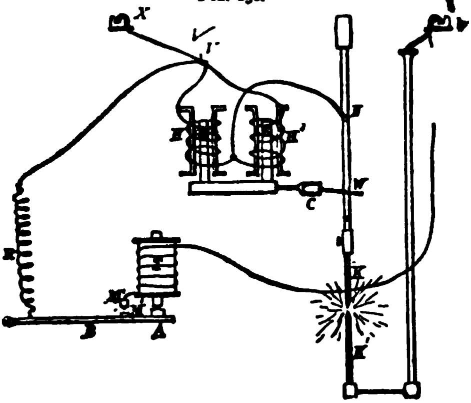


FIG. 257.



C. F. Brush. It was one of the first and it certainly remains one of the best of modern arc lamps. A great feature in its favour is the extreme simplicity of the mechanical contrivance. The principle is illustrated in fig. 258. The terminals X Y usually take the form of a pair of brass hooks which, by being dropped over horizontal pins on the under side of a suspending board place the lamp at once in the main circuit. The negative carbon K′ is fixed, and, being gradually consumed, the arc is steadily lowered in position, the upper or positive carbon K, falling at a corresponding rate.

Fig. 258.



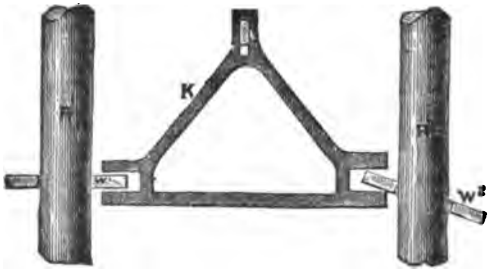
The current enters the lamp at the positive terminal X, and divides at V in the main circuit, passing through the low resistance coils H H′, in parallel in such a way as to generate powerful but opposite poles at the lower ends of the solenoids. On leaving the coils the currents reunite, and passing by a wire to the upper carbon holder N, traverse both carbons, the lower of which is connected to the negative terminal Y. The shunt circuit, the resistance of which is 450 ohms, is made by a thin wire passing from X round the bobbins H H′ in series, then round the cut-out bobbin T, from which it passes direct to the terminal Y. The thin coil on H H′ is wound outside the main coil. Connection is also made between V and the pivoted lever B, by means of a wire and resistance spiral R, but this will be again referred to presently.

Assuming the carbons K K′ to be in contact, the passage of the main current through the coils H H′ causes the soft iron cores N S and their horizontal yoke-piece to be drawn upwards. The yoke-piece is provided with a fork C, which tilts the washer-clutch W, causing it to seize the carbon holder and raise it sufficiently to strike the arc. Under normal conditions only about 1 per cent. of the total current passes through the shunt coils, but when the arc increases in length and thereby raises the resistance of the main circuit a proportionally larger current passes through the long thin wire coils on H H′. Being wound in the opposite direction to the few turns of the main coils, the shunt coils cause a diminution of the magnetisation of the cores or plungers N S, which therefore fall, and, causing the clutch W to loosen its grip of the holder, allow the positive carbon to fall, by the force of gravitation, until the length of the arc is so far reduced as to re-establish the normal division of the current through the main and shunt coils. We see then that the function of the thick wire coil is to tilt the clutch and strike the arc, while that of the shunt coil is to level the clutch, allowing the rod to slide and feed the carbon downwards. As a rule these reactions take place so gradually that the upper carbon is maintained at a uniform distance from the lower, and is simply fed at a rate corresponding with the consumption.

The 'cut-out' coil T performs a most important function. It is evident that should one of the carbons be burnt away or broken, or should from any other cause the maintenance of the arc become impossible, some device is necessary to introduce into the circuit an alternative path of about the same resistance as the arc circuit. The way in which this is accomplished in the Brush lamp is ingenious. It will be remembered that the shunt circuit includes a coil of many turns of thin wire on the bobbin, T. Now when the main circuit is broken, the whole current has to pass through the shunt circuit, and the coil T is so adjusted that when this increased current passes through it, but not otherwise, its core becomes sufficiently magnetised to raise the armature A, and with it the lever B. This lever carries the small contact stud M, and this on rising makes contact with another stud M′, which is connected to a short thick wire coil round T, the other end of which is connected to Y. It follows that under such circumstances a low resistance circuit is established from V, along R, and B, to M, and so on to Y.

Were it not for the high resistance of the shunt coils, they could be employed for this purpose, but under the circumstances such a plan is obviously impracticable. Of course as the main circuit is disconnected, the positive carbon-holder is not interfered with by the clutch, and can therefore, if only a portion of the carbon has been broken off, descend and re-establish the arc, when the current flowing through the thick coil on T will be diminished and the cut-out circuit disconnected.

FIG. 259.



Usually the Brush carbons are a foot long and last for eight hours or thereabouts. When, however, a longer period of lighting is likely to be required, lamps with two pairs of carbons are employed. The device for 'changing-over' from one pair to the other is purely mechanical and is illustrated in fig. 259. The positive carbon-holders R^1 and R^2 are parallel one to the other, and each is furnished with a washer clutch, as shown at W^1 and W^2. These clutches are operated by a small frame K, which is supported by the lever (shown in section at L) attached to the plunger or soft iron core of the striking and feeding solenoids. By the very simple device of making one of the forks in the frame K, higher than the other, this higher fork tilts its clutch before the other begins to act, and consequently lifts its corresponding carbon-holder a greater distance than does the other. At the moment when the first carbon is raised, it is short-circuited by the other, which the next moment is also raised. The arc then establishes itself across the lesser distance, and in all subsequent feeding and controlling movements the pair of carbons across which the arc was first started are alone affected, because, although both positive carbons are raised and lowered together, the ends of the reserve carbons never come into contact, and the E.M.F is insufficient to start an arc across the air space which separates them. When the one pair of carbons have been so far consumed that they cannot meet when the frame falls, the circuit is completed through the reserve carbons, and the arc established, after which it is maintained by the same apparatus acting in the same way as with the first pair.

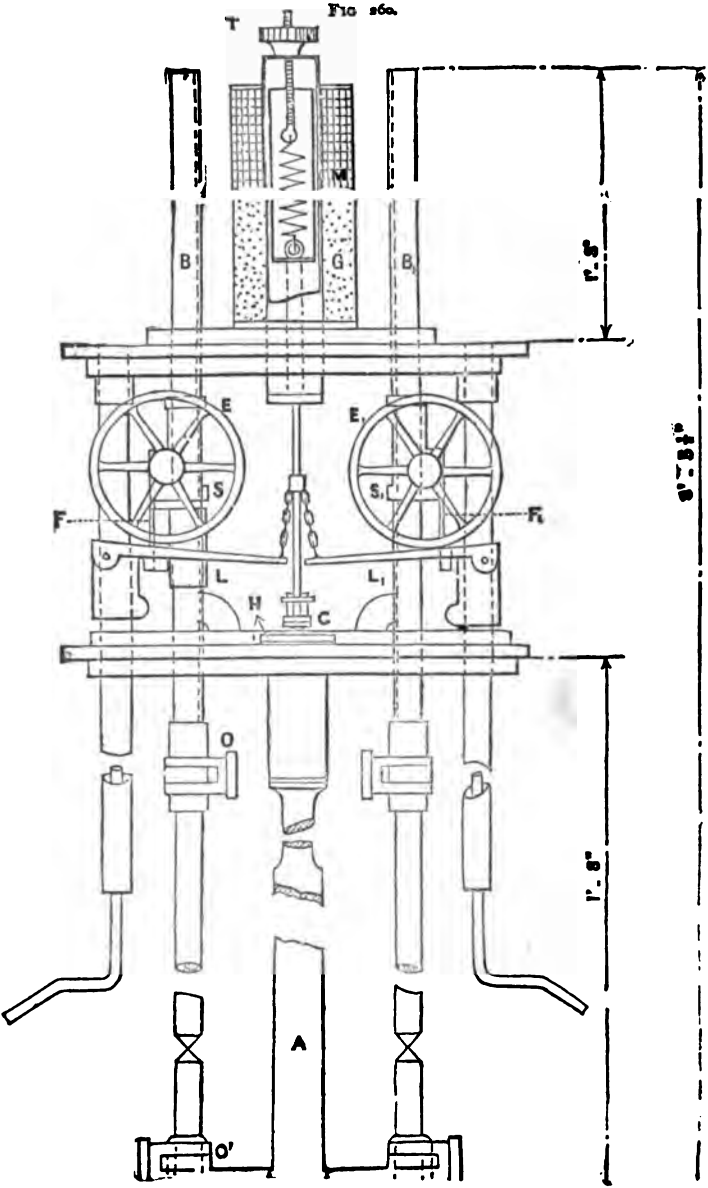
The construction of the double arc lamp invented by Messrs. Crompton and Crabb is illustrated in fig. 260.

The two positive carbons are carried by the rack-rods B and B_1. Sliding on each of these is a light gun-metal sleeve, S S_1, carrying spindles, to which are attached the two large brake wheels, E E_1, and between them the pinion which gears into the racks. These brake wheels rest upon a pair of levers, L L_1, the outer ends of which are pivoted to the framework of the lamp, their inner ends being connected by links to the core of the solenoid, which is placed in a central position vertically above the two inner ends of the levers. This solenoid is differential, G being the shunt and M the main coil, and the core is partially supported by a spring. The tension of this spring can be regulated by means of the screw T, which is turned to the right to increase its length, and to the left to decrease it.

Projecting vertically downwards from each sleeve, S S_1, to a distance from the centre of the spindle about equal to the radius of the brake wheels, is a stout pin or finger, F F_1, the action of which is interesting.

Suppose the rack-rod to be drawn up, then if the lever be pulled by the solenoid above the horizontal position, the whole weight of the rod and carbon is supported on the edges of the brake wheels, and the friction of them on the surface of the levers is sufficient to prevent their revolution ; hence this rack rod cannot run down. But if the levers be below the horizontal, then the weight is carried by the finger projecting from the sleeve, as shown at F ; the wheels are free to turn, the rack runs down, and continues to do so until the positive and negative carbon points come in contact. Now, if the current be switched on by its passage through the main wire of the solenoid, the levers rise, striking the arc, and at the same time applying the brake to the wheels. The combined action of the shunt and main currents on the solenoid core automatically adjust the length of the arc. If this becomes too great the increased current through the shunt draws down the core and levers, the brake wheels are left free to revolve, and the arc shortens. On the other hand, if the carbon points be too close

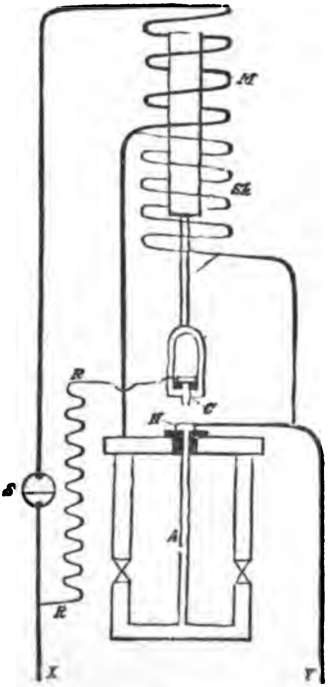
Fig 260.



the levers are raised, bringing with them the rack-rod and upper carbons. The fact of the finger projecting from one sleeve being longer than that from the other determines which pair of carbons shall begin to burn first, because, on switching on, that pair which has the longer pin will be the last to break contact, and will therefore originate an arc in so doing.

It will be seen from the diagram that on the core being raised the lever L$_1$ will apply the brake before the lever L does. Hence, it may be said, that the rack-rod B$_1$ gets a start on B; its carbon points are separated before those of B, and are kept a greater distance apart until the latter are consumed. At this stage the rack-rod B is prevented from further fall by a stop, and can no longer feed; hence the arc will lengthen, the shunt current will increase, and the other rod B$_1$, which can still feed, will be allowed to descend until its carbons touch, starting a fresh arc. When the second pair of carbons have burned low, the same action takes place, viz., further descent of the rod is prevented, the arc lengthens, the shunt current increases, and the core is drawn down, but lower than when the first pair of carbons were burned out, until a copper stud, C, attached to it makes contact with another stud, H, connected to the negative pole, thus cutting the lamp out of the circuit, and introducing an equivalent resistance.

FIG. 261.



The connections of the lamp and its equivalent resistance coil are shown in fig. 261. The current entering at X finds two paths open; the one through the resistance coil R R and insulated contact piece C, which for the time being is resting upon H, and thus

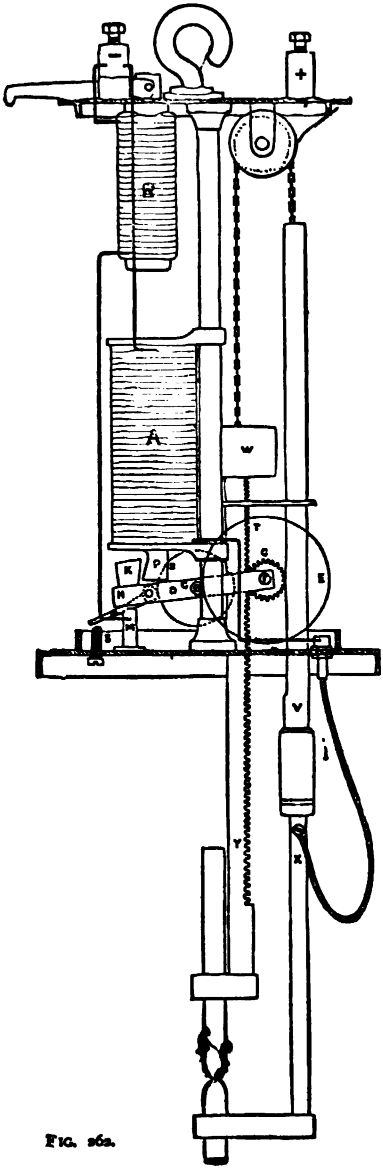


FIG. 262.

on to the next lamp; and the other through the switch S (which we suppose to be closed), the main solenoid coils M, the framework of the lamp, the positive carbon, the negative carbon, and ultimately out by H, and Y, on to the next lamp. The latter portion of the current in passing round the core magnetises it and draws it up, thereby breaking contact between C and H. Since nearly the whole of the current must now pass through the main solenoid, the core of the latter is definitely drawn up, lifting the two rack-rods, and establishing the arc between one pair of carbons, as explained above.

The Phœnix arc lamp is also of the differentially wound class. Its construction is illustrated in fig. 262, where A represents an electro-magnet wound with two coils, the pole-piece, P, of which acts upon an armature, K, fastened upon a frame, H D, pivoted at F. This frame also carries a brake wheel B, on the axle of which is fastened a small pinion G, and brake lever N made to grip B by a helical spring wound round the axis, by which it is attached to the frame H D. The pinion G gears into the larger toothed wheel E, on the axis of which is a pinion C engaging with the rack R of the positive carbon rod. This rod carries a weight W, which enables it in descending to lift the negative rod V X. When no current is flowing the brake lever N rests on the screw S, which releases the brake wheel and allows the carbons to come into contact. The current enters at the positive terminal on the right hand of the figure, passes through the framework of the lamp to the rod Y, and thence to the positive carbon. It returns from the negative carbon by the insulated rod X and flexible wire attached to it, passing through the thick wire coil on A, and from this to the negative terminal. The magnet attracts K, raising the frame H D, thus causing the lever N to grip the brake wheel and, by turning E and C, to raise Y and lower X for the purpose of separating the carbons and forming the arc. As the carbons consume, the difference of potentials at the terminals rises and the current in the fine wire coil round A, which is connected as a shunt to the lamp terminals, increases. This weakens the electro-magnet A and allows the frame H D to fall and the carbons to approach. When the lever N comes in contact with the screw S, the brake is released, allowing the carbons to approach as the consumption continues. If the carbons burn out, or if from any other cause the circuit through them is broken, the frame H D drops on the contact pillar M; this completes the circuit from the lamp frame through the German-silver resistance R to the negative terminal, thus preventing a break in the continuity of the circuit when several lamps are joined in series.

The Brockie-Pell arc lamp is illustrated in fig. 263; the main and shunt coils are wound on separate bobbins fixed parallel to one another, the main or series coil being that on the left side of the figure. The two cores pass through the ends of, and operate a 'see-saw' lever which is pivoted at its centre. The two carbon-holders are connected by a cord passing over a pulley wheel pivoted on the base of the lamp-case. The upper or positive holder is provided with a rack-rod which gears into a pinion; the spindle of this pinion works in the frame of the lamp and carries a comparatively large wheel having a strong broad rim, against which a brake in the form of a small leather roller is applied. The lever carrying this brake turns on the weighted sector-shaped lever, which is loosely pivoted but moves solidly with the brake wheel, its descent being, however limited by a stop ; the

FIG. 263.

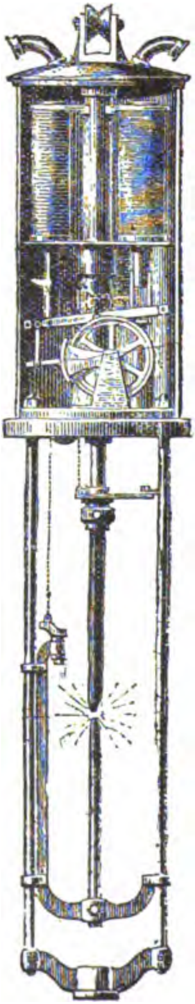
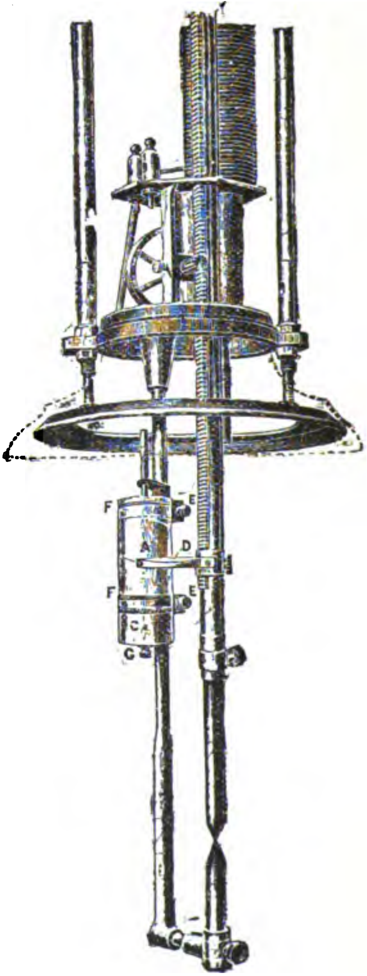


FIG. 264.

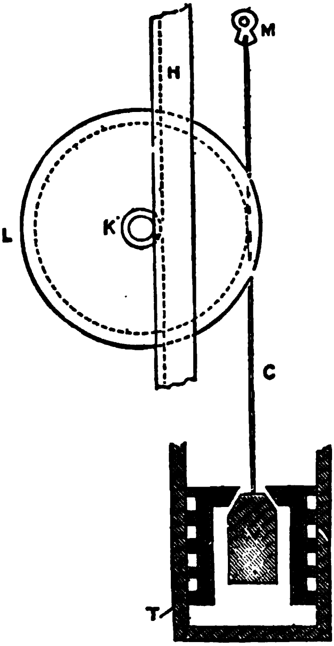


outer end of the brake-lever is connected with the link supported by the see-saw lever. The action of this mechanism can be readily understood. On the passage of the current the left-hand coil raises its end of the lever, applies the brake to the wheel, and raises the positive carbon, the negative carbon being caused to recede at the same time. The arc is therefore established. As the arc lengthens and the main current diminishes, the shunt current increases and the other end of the see-saw lever is elevated: consequently the brake lever is depressed, the brake wheel released, and the carbons allowed to feed together. These reactions take place readily, the feed being practically continuous, and a very steady light is the result. The initial adjustment for balancing the carbon-holders to operate with any particular strength, is effected by means of weights. As compared with the majority of lamps, the mechanism is simple and strong.

In fig. 264 is illustrated a form of arc lamp devised by Mr. J. G. Statter for workshop use. The lettered portion of the apparatus does not form a part of the lamp, but is attached for experimental purposes and will be explained presently.

The lower carbon is fixed, and the upper one is carried by a rack-rod which engages with a pinion carried on a horizontal spindle. On this same spindle, and just behind the pinion in the figure, is fixed a large grooved wheel round which passes a small chain. One end of the chain carries a peculiarly shaped weight, and the other end is fixed to the lower extremity of the core of the regulating solenoid, seen to the right at the top of the figure. Fig. 265 illustrates this arrangement more clearly, and also gives a section of the weight. H is the rack-rod which carries the upper carbon, and engages with the pinion K, while L is the large grooved wheel, on the same spindle as K, round which the chain C passes once. M is the point at which the chain is fixed to the core of the regulating solenoid. When it is required to separate the carbons and strike the arc, the core is sucked upwards into the solenoid, and pulling the chain upwards, causes the wheel L to revolve. This motion is imparted to the rack rod by the pinion, on the well-known wheel and axle principle, and the upper carbon being lifted through a small distance, the arc is struck. The chain is prevented slipping round the wheel, by the weight at its lower end. This weight is designed to prevent any sudden jerky movement of the rack-rod: it slides inside a brass tube T, and is made in two parts. The larger part is cylindrical in shape, having a series of grooves on the outside (as in some forms of high-speed pistons), and fitting accurately inside the containing tube. The inner portion, V, to which the chain is attached, is a valve whose seating is formed in the top of the outer weight. As all the surfaces fit closely, the compound weight cannot be drawn upwards quickly, but it may be lowered freely, since the valve then opens and allows the imprisoned air to escape. So long as the arc remains of the proper length, the pull of the regulating solenoid on its core keeps the chain taut, and by preventing the rotation of the wheel, holds the carbon in position. But when the distance between the carbons increases and it is required to feed, the current through the solenoid decreases and allows the core and the upper part of the chain M to drop slightly; the weight then touches the bottom of the tube, and the grip of the chain on the wheel being loosened, the wheel is free to move, and the carbon and rack-rod move downwards by their own weight. Immediately the proper length of arc is restored; the core again pulls at M, lifting the weight and fixing the wheel and rack-rod in position once more.

FIG. 265.



But it is necessary to arrange that the feeding shall be as delicate as possible, that is to say, the carbon must move downwards very slightly immediately the arc becomes even the least trifle too long. It will be observed that when the weight descends the outer portion reaches and rests upon the bottom of the brass tube first. The valve weight V is considerably the lighter part, and has a small amount of free play after the heavier part is resting on the bottom. Now the weight of V is just sufficient to allow the chain to grip the wheel and hold it in position, and when the lamp is running under normal conditions, this is the only portion of the weight acting; extremely light touches of V on the bottom of the tube slacken the chain enough to allow the wheel to move slightly, and a delicate feed is thus attained.

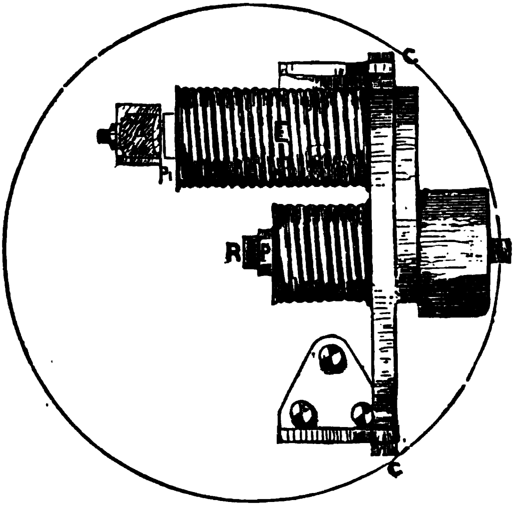
The lamp described is designed for constant potential or parallel working, but when it is required for use on the constant current or series system, the usual differential winding is employed, the resistance of the shunt coil being 100 ohms.

In another type of this lamp, the same feeding method is employed, but a different mode of striking the arc is adopted. The bearings of the brake-wheel spindle are carried by a lever, one end of which is connected to the core of the regulating solenoid; the rack-rod is then raised by the lever, without turning the wheel, to strike the arc.

Referring now to the experimental apparatus attached to the lamp in fig. 264. This illustrates an arrangement devised by Mr. Statter for the purpose of recording automatically the rate and regularity of the feeding of the carbons. A is a drum revolving about a vertical axis, and driven by a clock in the case C, just below A. One complete revolution is made per hour. The drum is covered with a sheet of ordinary squared paper. A light rigid arm, D, is clamped to the rack-rod, and carries a pencil which is kept pressed against the paper by a light spring. The distances on the squared paper parallel to the axis of rotation represent in fractions of an inch the length of carbon burnt; while one-sixtieth of the distance round the circumference corresponds of course to one minute of time. Before switching on the current the drum is given a complete revolution by turning the nut G, and the length of the arc struck is then recorded; this appears as a short vertical straight line on the paper. The drum then commences to rotate, while the pencil travels steadily downward with the upper carbon-holder. The method is practical, and is very useful for the testing of lamps and carbons.

The Gülcher lamp was designed for constant potential or parallel working, and has, therefore, neither a shunt coil nor a cut-out. It is consequently very simple in construction, as will be gathered from the plan given in fig. 266, and the elevation in fig.

FIG. 266.



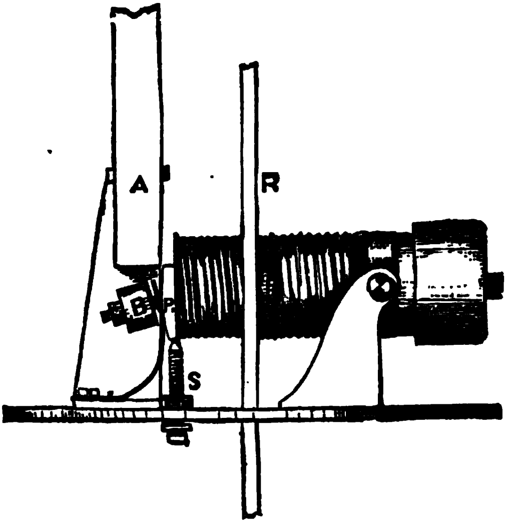
267. The regulation of the lamp is effected by an electro-magnet of the horse-shoe type, E, which is capable of rocking within certain limits, on the centres C C.

On starting the lamp the pole P attracts the iron rod R which carries the upper carbon, and holds it with a force proportional to the strength of the current flowing through the lamp ; at the same time the other pole, P_1, is attracted towards the fixed armature A, and the magnet moving upwards carries the upper carbon rod with it, and thus strikes the arc.

As the carbons are consumed the resistance gradually increases, and the current diminishing at a corresponding rate, there is less magnetic attraction towards the fixed armature ; the rocking magnet then falls to its original position of rest, supported by the stud S (fig. 267), and causes R to approach the lower carbon and so to maintain the arc, the current strength being at the same time increased proportionally.

As the consumption of the carbons is continued and the length of the arc therefore increased, the current is again diminished. With this diminution the magnetism is so reduced as to allow the

FIG. 267



carbon-holder R to slip until the arc reassumes its proper length, and the normal current is re-established, when the magnet is once more enabled to support the weight of the rod.

In practice the rod is continually slipping by imperceptible degrees, and compensating exactly for the consumption of the carbons.

To avoid sudden jerks in the action of the rocking magnet, a magnetic brake B is employed, which introduces friction in inverse proportion to the length of the arc. The two carbon-holders are connected by a cord passing over a pulley wheel, so that the two carbons approach or recede simultaneously.

The lamp is constructed in various forms, but in all of them the same simplicity of parts is maintained. The globe is fitted to a pair of sliding rods and can be drawn down out of the way so as to expose the carbon-holders and facilitate the renewal of the carbons.

CHAPTER XVI.

INCANDESCENT LAMPS—PHOTOMETRY.

IT was shown when discussing the Cardew Voltmeter, that if a current of electricity is urged through a solid conductor, heat is developed, and that the amount of heat so developed is proportional to the total energy expended in the conductor. It was also shown that this energy is proportional to the product of two factors, viz., the strength of the current C, and the difference of potential E between the extremities of the conductor, necessary to maintain that strength—or the heat H developed is proportional to $E\,C$; but by Ohm's Law $E=C\,R$, therefore $E\,C=C^2R$.

It is manifest from these simple formulæ, that the heat developed varies directly as the resistance, and directly as the square of the current strength. It may also be said to vary directly as the potential difference. If we have two equal and uniform conductors A and B, and maintain a potential difference at the ends of one of them, A, twice that of the other, B, the heating effect will be quadrupled; for with equal resistances the current strength will also be doubled, and in fact energy is being expended four times as fast in A as compared with the rate of expenditure in B. If, however, while both conductors are of the same length and sectional area, the specific resistance of B is twice that of A, and the same potential difference is maintained in both of them, the resistance of B being twice that of A, will halve the strength of the current flowing through B. Hence if in A, $H = E\,C$, or C^2R, then in B, $H=\frac{1}{2}CE$ or $2R\left(\frac{C}{2}\right)^2=\frac{1}{2}C^2R$. In this case twice as much heat is developed and twice as much energy is expended in A as compared with B. Again, if the current in B is made equal to that in A, by doubling the potential difference in the former, then in A, $H = EC$ or C^2R, and in B, $H = 2EC$ or $2C^2R$, so that doubling the resistance and keeping the current strength constant, doubles the heat developed and causes twice the amount of energy to be expended. One great lesson is here again enforced, viz., that the amount of energy obtained in the form of heat can only equal and never by any possible means exceed the amount of electrical energy expended or absorbed in the conversion.

The relation between heat and temperature has already been discussed, but we must again refer to it here, for it is of the utmost importance. Let us suppose that instead of employing a conductor of increased specific resistance, we experiment with two samples of the same material and of the same sectional area, but that one of them, B, is twice as long as A; then the resistance of B will also be twice that of A, and if equal currents are urged through these conductors, the heat developed in A will be only half that developed in B; but as B is twice the length of A and has therefore twice as much matter in it, the temperature of the two conductors will be equal. Now when a body is made very hot it becomes luminous, and the luminosity of a body is proportional to its temperature. In this experiment, therefore, the temperature of A and B being equal, the luminosity will be equal, although B absorbs twice as much energy as A, because its resistance is double Now if the resistance of B is made double that of A by halving its sectional area instead of by doubling its length, and equal currents be urged through each as before, we still get twice as much energy absorbed, and therefore twice as much heat developed in B as in A. And since the mass, or the quantity of matter in B is now only half that in A, equal quantities of heat would cause the temperature of B to be twice that of A: therefore as twice the amount of heat is developed in B, its temperature is raised to four times that of A. This clearly indicates the direction in which we should work in order to raise a conductor to a very high temperature. Stated generally, a large amount of energy must be expended on a small mass of matter; therefore the conductor must have a high resistance, and in order to keep its mass small this high resistance must be obtained by diminishing its sectional area rather than by increasing its length, and further, the material chosen should be one which has a high specific resistance.

Men were not long in conceiving the idea of employing the heating effect of a current upon a conductor for illuminating purposes, and patents based upon this principle were taken out nearly fifty years ago. But these early efforts were one and all of them failures from a commercial point of view, although some of them were identical with many of those of a comparatively recent date. It was seen that a conductor of high specific resistance was necessary, and this limited the number of materials available. This number was further reduced by the fact that most conductors either melt or volatilise at comparatively low temperatures—before, in fact, the temperature of white heat is attained. Iron, which is cheap and has a high resistance and which might therefore be considered a suitable substance, unfortunately melts at a comparatively low temperature. It is for this reason useless as an illuminant. It also oxidises or combines with the oxygen of the air as its temperature rises. German silver is for similar reasons not available. We are, indeed, limited among the metals to the expensive platinum or its alloys, unless we take into account the experiments which have been made with iridium, a most expensive and very scarce metal, and which, if equal to the requirements, could probably not be procured in sufficient abundance to meet the demand. Platinum is capable of being raised to a bright white heat, and can then emit light of dazzling brilliance. It has also the advantage of being practically inoxidisable. The critical temperature is, however, suddenly reached; that is to say, above a certain point, a slight increase of temperature suffices to produce liquefaction, and therefore to cause a rupture and so disconnect the circuit. It must also be remembered that the resistance of metals increases materially with an exaltation of temperature, a fact which hastens the fracture of the wire. Efforts have been made to prevent this overheating by means of automatic regulators, which short-circuit the lamp when the current reaches a certain predetermined strength, and so cuts off the current just at the moment that there is a risk of breaking the wire. Some of these are clever laboratory expedients, but nothing more. If, then, we had been restricted to metallic conductors, electric lighting by incandescence would long since have been given up as impracticable. Carbon, however, which is a non-metallic body, is a fairly good conductor of electricity, although of considerably higher specific resistance than platinum. A very remarkable feature pertaining to it is that its resistance decreases with an increase of temperature. It is a substance which cannot by any ordinary means be melted or volatilised (although a temperature has been attained at which it becomes flexible), so that in this respect it is superior to platinum or any other of the metals. It however oxidises readily when heated in an atmosphere containing free oxygen, such as ordinary air. This difficulty was for a long time insurmountable, although many efforts were made to overcome it, such as placing it under a glass receiver or shade, and depriving the enclosed air of its oxygen by means of a piece of phosphorus, a substance which oxidises readily at ordinary temperatures. In this case, the carbon is suspended in an atmosphere of the remarkably neutral or inactive gas nitrogen. But even such an arrangement as this was soon found to be clumsy, unsatisfactory, and in fact impracticable. Even supposing it to have been otherwise, the carbon procurable was very defective. Thin rods of graphite or gas-retort carbon such as is used in the Bunsen cell, or sections of the artificially prepared material such as is used in the Leclanché cell, were tried; they could not, however, be obtained of sufficiently small sectional area, and were too irregular in structure to prove practicably useful. Efforts were also made, and with a better prospect of success, to accomplish the object in view, by placing the carbon in the then best obtainable vacuum. The vacua were for a very long time far from perfect, and as a consequence the durability of the carbons was very brief, but when it was shown how it was possible to secure an all but perfect vacuum, a fresh impetus was given to the idea of lighting by the incandescence of thin pencils or, as they were subsequently called, filaments of carbon. Since then, the real improvements that have been made have been in the formation and fixing of these filaments, which can now be prepared from almost any substance having a large proportion of carbon in its composition. As organic substances consist to a great extent of carbon, and as these substances can generally be decomposed somewhat readily, it is only natural that they should form the basis from which the filaments are manufactured. Filaments as they are now made, can be divided into two classes, (1) those in which the fibrous structure of the carbonaceous body is retained, and (2) those in which the original or organic structure is altogether destroyed during the process of manufacture, and the material rendered thoroughly homogeneous. To the first class belongs the Edison lamp, and to the second class, the lamps of Swan and the majority of other inventors. It is a remarkable fact that Edison asserted in his patent that to give the carbon the highest possible resistance and the smallest tendency to disintegration, it should retain its structural character, and that such carbons alone possess these qualities, qualities which are impaired by any treatment tending to fill up the cells or pores with unstructural carbon, or to increase the density or alter the resistance of the fibre. Swan, on the other hand, maintained that the structure of the material should be entirely destroyed, and the carbon filament made as dense as possible. Although good and efficient lamps can be manufactured on either of these principles, experience seems to show that the latter or homogeneous filament is the better of the two.

In attempting to deal more specifically with the manufacture of incandescent lamps, we are met with two serious difficulties: the first is due to the enormous number of processes which have been introduced, but to the great majority of which the limits and purpose of this work will not permit us to refer. Legal decisions which have been given in recent actions between the various makers, have however considerably reduced the number and variety of processes actually in use. The second difficulty arises really from a kind of jealous fear, for the practical makers of lamps regard their methods as secrets which it is their bounden duty to keep religiously to themselves.

It might have been gathered from what has already been said that the chief desiderata in a good lamp are, (1) that the filament shall be sealed in an airtight vacuous glass vessel; (2) that efficient means shall be provided for connecting the filament with the external circuit; (3) that the filament shall offer considerable resistance; (4) that it shall have a small mass, so that its temperature shall be raised as much as possible by a given quantity of heat; (5) that it shall be durable at high temperatures in a vacuum; and (6) that the lamp shall be capable of being manufactured at a small cost, and of any desired dimensions or resistance. At present it is the last of these requirements which gives the greatest trouble in meeting, because a slight variation either in the thickness or sectional area, or in the amount of radiating surface of the filament, causes a considerable difference in the luminosity.

The filament in the Swan lamp is made either direct from cotton thread, or from a thread formed by squirting a solution of cellulose through a fine nozzle at high pressure, cellulose being the chief constituent of such vegetable substances as cotton, linen, paper, &c. The first process with the cotton is that of parchmentising it. This is no secret, the method adopted being the same as that for making ordinary parchment paper. A solution of two parts of sulphuric acid to one part of water having been prepared, the cotton thread (which should be of a loose texture such as knitting or crochet cotton) is wound on a drum, from which it is passed slowly through the acid solution. During the passage the acid acts on the fibres and gradually destroys their molecular structure, partially dissolving the material, and converting it into a gelatinous semi-transparent state, as cellulose, having a chemical composition of $C_6H_{10}O_5$. Having been brought to this condition it is passed over freely revolving rollers or pulleys into a bath of running water, where it is slowly and uniformly wound on to a large perforated metallic drum driven by machinery. When the drum is covered it is removed and placed in another water bath, to ensure a thorough washing. It is absolutely essential that every particle of acid should be removed, for were any left behind, it would on drying destroy the thread by dissolving it. After being thus thoroughly washed the drum is removed from the water and placed aside, to allow the thread to dry. When first placed in the washing bath it gradually loses its transparency, becoming white and opaque. But on drying, it returns to the transparent state, with the additional property of being remarkably tough, becoming a horny thread, with every trace of the original twist destroyed.

This process can be carried out in a small way, and is very instructive. A piece of knitting cotton is wound round a piece of glass, or better still, round a frame made of pieces of glass rod. It is then dipped into the acid solution of the proportions above mentioned. The process must be carefully watched, and if the action has been of just sufficient duration, but not lasting too long, the change from the fibrous to the homogeneous state will be readily seen. It should then be placed in water, well washed and dried. The drying is best performed by stretching the thread gently in a straight line, or if too lengthy, over a series of pulleys. If the thread is left in the acid too long, the solution is carried too far and the thread weakened, so much so as not to be able to bear its own weight even in a length of a few inches. The same thing happens if the thread on being removed from the acid is placed on a plate or piece of glass, instead of being at once immersed in the water; the acid remaining in the thread completes the dissolving process and liquefaction ensues. It is possible to remove the thread from the acid too soon, the defect then being that the destruction of its fibrous character is only partly performed.

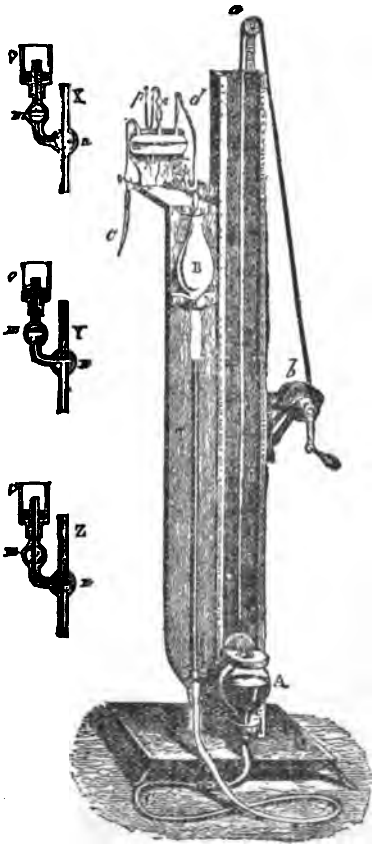
The thread having dried, it is next cut to a uniform gauge throughout, which is done by drawing it through a series of jewel dies decreasing slowly in diameter. It is then subjected to the process of 'carbonising,' or converting it into a solid carbon filament. The thread is first wound on a frame consisting of two round carbon or porcelain rods kept in position by being fixed into holes in two side-pieces. The round rods are sufficiently far apart to make each bend of the thread correspond to one filament, for it is in the process of carbonising that the filament is definitely shaped. In order to make the loop, which was at one time one of the characteristic features of the Swan filament, the thread is turned twice round one of the carbon rods in the frame before passing to the other rod. One object of this formation is to get a long filament in a comparatively small bulb. The frame having been filled, pieces of cardboard are placed on its sides or faces to prevent accidental injury to the threads, the whole being then wrapped round with paper. A number of such parcels is placed in a crucible or cast-iron box, until the vessel is nearly full. Powdered charcoal having been shaken over the contents to fill up any spaces that may have been left, the lid is placed in position, and an airtight joint made with a little fireclay. As the powdered charcoal gets hot it absorbs any free oxygen that may be in the crucible and prevents any getting to the filaments; were it to do so, it would speedily destroy them. The crucible being thus prepared, is placed in a suitable furnace and raised slowly to a white heat. The gradual increase of temperature is important in determining the shapeliness of the filament. Too rapid an increase in temperature would alter the dimensions of the frame and cause the threads to sag, so that the form of the filaments would be more or less distorted. The high temperature is necessary to render the carbon hard and durable, to increase its conductivity, and to reduce its capacity for holding atmospheric and other gases within its pores. This last-mentioned feature is not only interesting, but it is also fraught with the utmost importance. All substances are more or less porous, and have the power in varying degrees of holding gaseous particles within those pores, a power or property known as occlusion. As the temperature of a body rises these gaseous particles expand and force themselves through the substance, frequently causing minute fissures ; with some substances which do not liquefy, such as carbon in its ordinary form, this power of occluding gases returns with a resumption of the normal temperature. It is, therefore, imperative that the nature of the carbon should be so altered as to prevent this taking place. Hence the necessity for thorough carbonisation at a high temperature.

This alteration in character of the carbon is continued in the next process, which is that of 'flashing.' Before proceeding with this process, however, the filaments are cut to about the desired length, sufficient margin being allowed for making connection with the platinum wires, which pass through the bulb to the external circuit. The filament is then held by a pair of clips connected with suitable terminals, by means of which a dynamo, or better still, a battery of secondary cells, can be joined on. The suspended filament is then placed in an atmosphere of some hydro-carbon, more generally ordinary coal-gas (which is rich in carbon), and traversed by brief currents sufficiently strong to raise it, or portions of it, to a white heat. The effect of this process is to partially decompose the gas, which is at the ordinary atmospheric pressure, and to cause a deposition of carbon particles on the surface of the filament. Should there be, as is generally the case, any inequality in the filament, causing a variation in its resistance, one portion will be raised to a higher temperature than another, and upon this hotter section a greater deposit of carbon will take place The flashing process is therefore continued until the carbon assumes a uniform temperature, that is to say, until it becomes uniformly luminous throughout. The process also serves to reduce the power of occluding gases in the interstices between the particles. The filament is next placed in an exhausted receiver, and a continuous current passed through it, the result being that the carbon is hardened, the conductivity increased, and the power of occlusion eventually destroyed; but to bring about these results the temperature must be raised to a white heat, the current being maintained until the resistance is reduced almost to the required limit. The final flashing may, however, be reserved until the filament is fixed in the bulb and ready for finishing off. Platinum wires are always employed in mounting the filaments, as it is the only metal which has a coefficient of expansion nearly equal to that of glass; that is to say, it expands or contracts with variations of temperature at almost exactly the same rate as glass, so that it can be fused into that material without any risk of its subsequently fracturing the glass on cooling. The wires are first fused along the sides of a short piece of glass rod, or have a little molten glass twisted round them while they are held in position. In the former case, a piece of glass tubing is fused over the rod, thereby encasing the wires for a portion of their length. The connection with the carbon is made by flattening out the ends of the wires into minute plates, which are then bent gently round the ends of the filament, to which they are fixed with carbonaceous cement. The joint is completed by carbonising the cement by means of a strong current sent through it. Instead of using the cement, the joints are sometimes perfected by immersion in a hydro-carbon liquid or gas, the filament being short-circuited and the joints raised to incandescence by a strong current, causing a decomposition of the hydro-carbon, and a deposition of the carbon upon the joints. There are several other methods of mounting, but they are mostly based upon or are modifications of those above described.

The next process is that for exhausting the bulb of its contained air and moisture. This has to be performed carefully, and it is here that some of the greatest difficulties are met with.

The vacuum obtainable in an ordinary mechanical air-pump is, as we have already indicated, far from perfect, and useless for the purpose. There are, however, two types of mercurial air-pumps which are so far superior to the mechanical form that they can produce even higher vacua than are actually required for lamp-making. It is, of course, well known that if a long glass tube, say 36 inches long, sealed at one end, is filled with mercury and then inverted with its open end under the surface of mercury contained in a basin or other convenient vessel, the liquid metal in the tube will sink until its surface is about 30 inches above that of the mercury in the basin—until, in fact, just a sufficient height of mercury is left in the tube to balance the atmospheric pressure on the mercury outside. It follows that the space in the tube above the level of the metal is a more or less perfect vacuum, and it is generally known as a Torricellian vacuum, owing to the fact that Torricelli was the first to perform the experiment.

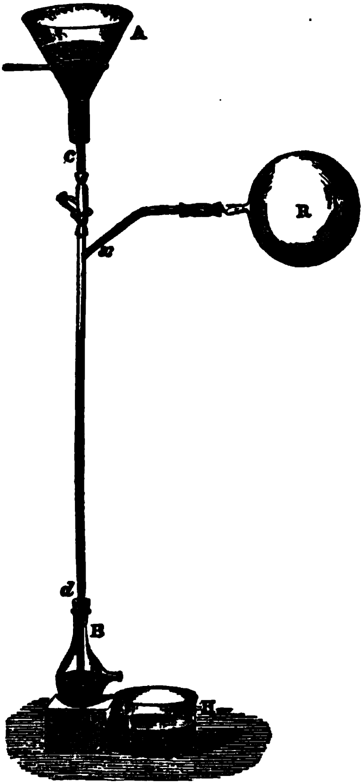
FIG. 268.



The Geissler pump, although but a modification of the Torricellian apparatus, is an instrument of incalculable value. A laboratory form of this pump is illustrated in fig. 268. A is a glass vessel or reservoir which is connected by a piece of flexible tubing, C, with a barometer tube, T, terminating, at its upper ex tremity, in a glass reservoir, B, which may be called the pump-head The latter reservoir is connected to a three-way tap, *n*, of which enlarged views are given at X Y Z. When this tap is turned, as at Z, communication between B and the outer air at *v* is established, an additional ordinary tap being, however, interposed at *m*. When *m* is turned off, as at Y, communication with the outer air is shut off; but if *n* is turned into the position shown at X, the pump-head is connected to the tube *d*, which leads into the drying tube *o*, containing sulphuric acid. The receiver or other vessel to be exhausted is connected to the tube *c*, which also leads into the drying tube. A small manometer or pressure gauge, *p*, also communicates with *o*, and serves to indicate the degree of exhaustion obtained. The reservoir, A, has a cord attached to it, which, passing over the pulley, *a*, is fixed to the drum, *b*. By means of the handle attached to this drum, the reservoir can be raised or lowered through a distance of nearly 4 feet.

If now A is placed at the top of its range, the taps *n* and *m* being open as at Z, the mercury on being poured in will fall down the tube C and rise in T until the pump-head, B, is full, or until the mercury columns in the two tubes are balanced. The air in T and B will, of course, be expelled at *v* as the mercury rises in the tube. Supposing the taps to be next turned so as to shut off communication with the outer air and connect B with the receiver or incandescent lamp bulb which is to be exhausted, and then the reservoir, A, to be lowered sufficiently, the mercury will flow out of B and down T until it is just balanced by the pressure of the air on the surface of the mercury in A. The air in the receiver or bulb then expands uniformly so as to occupy the space in the pump-head and tube above the mercury. The tap *n* is again turned so as to shut off the receiver. On raising the reservoir, A, the mercury again rises into B, and the taps being turned so as to open communication with the atmosphere, the contained air is driven out. This done, *n* is once more turned so as to open communication between the receiver and B, and cause the air left in the receiver to again expand when A is lowered. This air is in its turn expelled, and the process repeated. The operation is obviously a very slow one, although it is possible with this apparatus to obtain very high vacua.

FIG. 269.



The other type of mercurial pump to which we have referred is the Sprengel, the fundamental principle of which is illustrated in fig. 269. It consists of a stout glass tube, *c d*, 39 or 40 inches long, with a branch *x* connected to the vessel R to be exhausted. A large funnel-shaped reservoir, A, supported by a stand, is connected to *c d* by means of a piece of india-rubber tubing, the size of the channel through it being adjusted by means of a pinch-cock. The lower end of *c d* dips below the surface of the mercury in the flask B, which is furnished with a spout a little higher than the bottom of *c d*, in order to allow the mercury to pass out into the reservoir, H. The pinch-cock is so adjusted as only to allow the mercury to pass down the shaft a drop at a time. Each drop constitutes a plug or piston which fits closely to the sides of the glass and in its descent drives before it any air that may happen to separate it from the drop beneath it. The shaft *c d* is to all intents and purposes a barometer, so that the drops of mercury accumulate until a column is formed about 30 inches high, the actual height depending upon the counter-pressure of the outer air at the time being. Hence the distance which the mercury pistons ultimately fall is only 9 or 10 inches It will be evident that as the drops fall, and tend to establish a vacuum above them, the air in R expands and part of it occupies this otherwise vacuous space. Consequently as each piston passes the junction of *x*, the air is swept out little by little until finally a very good vacuum is obtained in R. When the degree of rarefaction becomes considerable, the pistons fall smartly upon the column of mercury and give out a distinct metallic ringing sound. This hammering frequently sets up such strong vibrations as to fracture the glass; and it is this which really limits the length of the shaft. As the mercury falls on the barometric column, an equal quantity is, of course, driven out at the lower end, carrying with it, also, the bubbles of air which separate the little plugs. The mercury collected in H is replaced in A as necessity arises. This process is also very long and tedious.

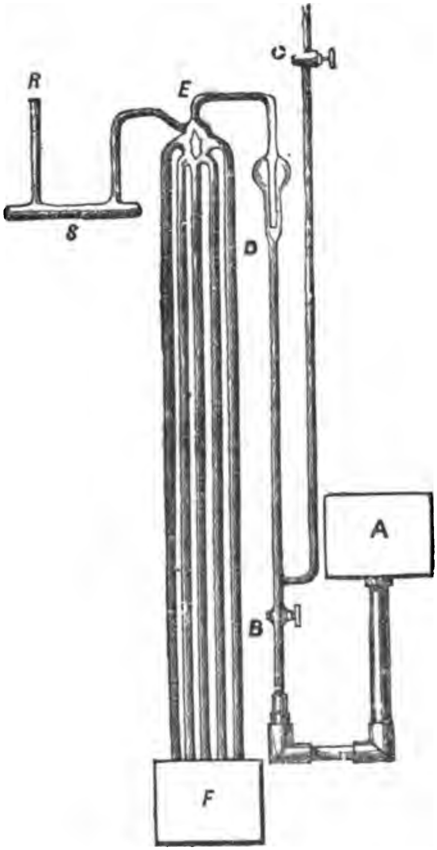
The exhaustion can be materially hastened by employing a good mechanical air-pump to exhaust the system as far as possible by mechanical means, the process being afterwards completed with the mercury pump. A simple barometer gauge can also be used to indicate, by the height of its contained mercury, the degree of exhaustion obtained.

These are the two systems of pumps upon which the apparatus actually employed in exhausting incandescent lamp bulbs is based. These simple forms are, however, open to many serious objections. A film of air always attaches itself to the surface of glass, and at times some difficulty is encountered in getting rid of it. Air is also supposed to be confined in the mercury itself, but there is some doubt on this point. To get rid of other impurities the mercury should always be distilled, and never allowed to get dirty by contact with brass or any other substance which it is likely to attack. Ordinary air always contains more or less moisture, and to get rid of this the air as it is exhausted from the lamp bulb is made to pass through sulphuric acid or phosphoric anhydride in order to dry it before it is allowed to enter the pump. Grease used for lubricating taps is also injurious for similar reasons, and should, therefore, be avoided. Taps themselves are serious offenders. No matter how perfectly they are made, they must allow some air to enter the pump, more especially when high vacua are obtained, and when, therefore, the pressure of the outer air on the tap is very considerable. To overcome this difficulty, taps are now superseded in the essential portions of the pump by small glass valves moving up and down in the pump as the mercury rises and falls. Their ends are ground to fit the seating, the passage being effectually sealed by a small ring of mercury which is retained as the valve drops into position. One of these valves is shown at D in fig. 272.

But mercury, like other bodies, is more or less volatile, and when the exhaustion in the pump is carried beyond a certain point, the exceedingly small pressure on the mercury surface permits vaporisation to take place. Although the degree of exhaustion of incandescent lamp bulbs is comparatively low, and not sufficient to cause any considerable amount of vaporisation, it may be interesting to mention a device by Mr. Crookes for keeping the vapour out of the receiver to be exhausted. Between the receiver and the pump he placed a long tube containing in the middle of it a little iodine, on each side of which was placed powdered sulphur. The mercury vapour was arrested by the iodine and converted into solid iodide of mercury The iodine, which is itself volatile, was prevented by the sulphur from getting out of the tube either way, by its conversion into iodide of sulphur. But there was also a risk of the sulphur getting out of the tube, and this was prevented by placing in its path powdered silver, which, combining with sulphur vapour, would form sulphide of silver. In this way it would be possible to prevent any mercury passing into the receiver, which would, therefore, contain nothing but the exceedingly minute residuum of air.

One of the most practical forms of pump is that of Mr. Gimingham, the factory type of which is illustrated in fig. 270. A large vessel, A, is employed to supply several pumps, the flow of mercury through each pump being regulated by the tap, B. The mercury is driven up the tube D and enters the pump-head at E, where the drops are divided between five Sprengel fall-tubes, carrying with them the air from the lamp bulb attached to R, which on its way to the pump passes through the horizontal drying tube S. The mercury plugs fall into the reservoir F, whence the metal is lifted by a force-pump into A again. But as the mercury is very liable to carry with it minute air-bubbles, which would be given up in the pump and impair the vacuum, some device becomes necessary for arresting these atmospheric particles. The bubbles usually find their way to the surface of the glass, and slide upwards with the mercury. This fact permits the adoption of a very simple but effectual form of 'air-trap,' as shown near the top of the tube D. The tube is at this point enlarged to a bulb, through the top of which is fused the tube leading to E. This inner tube is open at its lower end, which is clear of the outer tube, so that the mercury on rising passes freely through it on its way to the pump, while the air-bubbles continue their course along the surface of the glass, and are consequently arrested or trapped in the upper part of the bulb.

Fig. 270.



A more elaborate form of the same pump is shown in fig. 271, for which we are indebted to the Council of the Society of Arts.

The supply vessel A communicates by a long flexible tube with a forked tube *c*. The tube on the left, which is controlled by the pinch-cock *r*, leads through two air-traps, *n*, *m*, to a McLeod pressure gauge, an appliance used for measuring the pressure in very high vacua where the ordinary means of measurement are not available. The process consists in compressing a large but known volume of the rarefied air into a comparatively small space also of known dimensions, and then measuring the pressure under the altered conditions. The tube on the right, controlled by the pinchcock *q*, leads through the air-traps *h*, *i* to the pump-head, where the mercury divides between the five fall-tubes, which are about 39 inches long, and which discharge into the capacious reservoir shown at the bottom. The tube *t* is the exhaust tube, having three branches, one, *s*, leading to the McLeod gauge, another, *l*, to the barometric gauge, *u*, and another through the drying and absorbing tubes, *x* and *y*, to the lamp bulb. A comparison barometer is placed at *w*. The supply vessel A is lowered from time to time and communication established

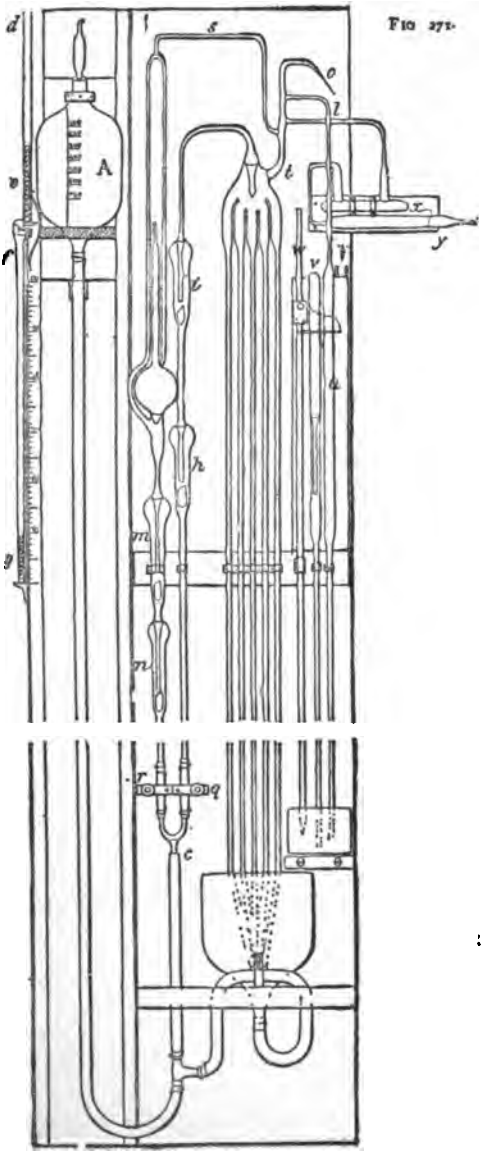


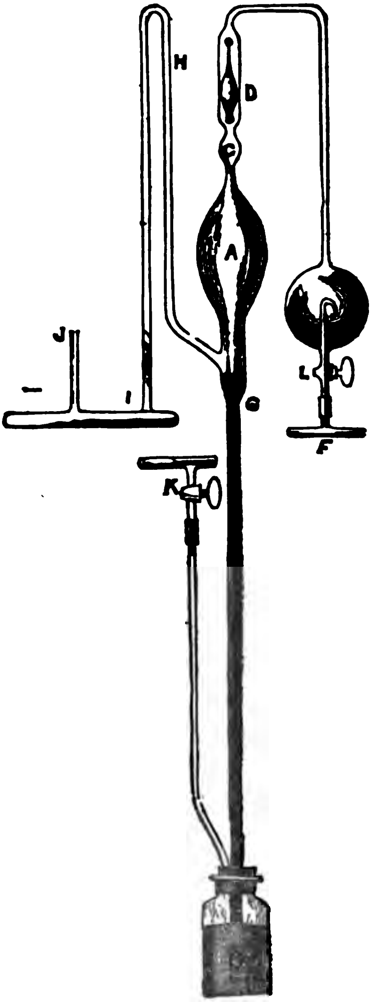
FIG. 271.

with the collecting vessel so as to allow the mercury after it has passed through the pump to refill it. In experimenting it is sometimes necessary to count the number of times this vessel is raised; this is done automatically by the tubes *d e* and *f g* with the aid of a few leaden shot, one shot being made to fall from the upper to the lower tube every time the vessel A is raised. Mr. Gimingham has experimented very extensively with mercurial pumps, and finds that 39 inches is the best length for the fall-tube. He says that 'An experiment recorded in my note-book with a five-fall-tube pump whose tubes were at first made 33 inches long, and then were lengthened to 39 inches by sealing pieces to their lower ends, shows that by passing the same quantity of mercury through at the same rate, a certain globe was exhausted in the first case to 50 mm. pressure, and in the second to 1 mm., showing a great increase in the rate of exhaustion, due to the extra 6 inches of fall-tube. On the other hand, if they be made of a greater length than 39 inches the fall of the mercury at the high exhaustion causes such severe hammering that the tubes are liable to be fractured.'

From other experiments he deduced that in the higher stages of the exhaustion, the air particles, instead of being swept out by the pistons, are taken out by a process of entanglement with the mercury.

Mr. Swinburne has invented an exceedingly simple and useful pump (fig. 272). It consists of a bulb, A, on a long shaft, G, which passes through an air-tight stopper nearly to the bottom of the bottle B. The bulb is drawn to a point at the top, and the tube is enlarged into a little bulb at C. It is again contracted where it joins the valve tube D. From the top of D there is a tube to the globe E communicating with the tube F, which serves for a number of pumps and in which a vacuum is maintained by a mechanical pump. H leads to the drying tube I, and J to the branch tube on which the lamps are sealed. The pump is started by opening the tap I, but the bent tube leading into the globe E is drawn very fine so that the exhaustion takes place gradually. The bending in this tube prevents any globules of mercury that may be drawn over into E from getting into the vacuum tube F. When the vacuum in the pump and lamps has been brought to about half an inch, communication with F is cut off by turning the tap L and the tap K is opened, and a higher vacuum developed by subjecting the mercury in B to alternations ordinary atmospheric, and high air pressure. The height of the mercury shown in the shaft G is that due to the ordinary atmospheric pressure in B, so that when the high-pressure air descends through K, the mercury is driven past the opening of the tube H, through the bulb or pump-head A, through C and half way up the tube D. The extra pressure being now removed from B, the mercury descends, the valve in D closing the opening into C before it has all fallen so that the valve is sealed by the mercury. The mercury continues to fall till it reaches the level G, whence a further exhaustion by expansion from the lamp bulbs takes place. This small quantity of air is in its turn expelled, and the Geissler action continued until the necessary degree of exhaustion has been obtained. The little bulb C is introduced to prevent the mercury rising and hitting the valve smartly when the exhaustion approaches completion. Were it allowed to do so the air would probably be driven against the side of the glass and stick there. It will be evident that, as the passages both above and below D are exhausted, a very small pressure will suffice to raise the valve.

~ 272.



Reverting to fig. 269, it will be apparent that if the atmospheric pressure in B is reduced the mercury column in the shaft *c d* will be shortened, whence a shorter shaft will suffice. In pumps of this pattern recently devised by Mr. Stearn, there are three fall-tubes, each 10 inches long, completely enclosed in a partially exhausted chamber.

Such pumps are finding considerable favour, but they introduce a further risk, for, if anything happens to interfere with the partial vacuum, the mercury will be driven up with considerable force and get into the upper parts of the pump, possibly breaking it.

Many suggestions have been made to heat portions of the mercury pump with a view to hastening its action, and pumps have been constructed to suit this purpose, but they do not seem to have met with much success in practice. Vacua can now be obtained far in advance of the actual requirements, the most perfect vacua being developed by the absorption of the residual gas after the exhaustion has been pushed as far as possible by the mercury pump. This is done either mechanically or by using some substance with which the air particles combine chemically. Dewar has produced a vacuum, which he estimates at $\frac{1}{350}$ of a millimetre, by heating charcoal to redness in the vessel exhausted by the Sprengel pump.

Mr. W. Crookes says he has obtained a vacuum of one-hundredth of a millionth of an atmosphere, which is equivalent to one-tenth of an inch at the top of a barometer tube 200 miles in height. That would appear to be an almost perfect vacuum; but such is the smallness of the molecules of matter, that, were a small tube containing a centimetre of air exhausted to that extent, there would still be left in it ten billion molecules.

Although it is, evidently, a comparatively simple matter to obtain the degree of exhaustion necessary for incandescent lamps, there are several causes for a deterioration manifesting itself in the vacuum after the finished lamp has been laid aside for a time, such as the occlusion of gases by the carbon and platinum, and by the cement employed to connect them together, and the very thin film of air which is liable to adhere to the inner surface of the bulb. In order to expel these gases, the filament is raised to incandescence during the later stages in the process of exhaustion, or the heat is applied externally.

The lamp having been sufficiently exhausted, the small glass tube connecting the bulb to the exhaust tube is fused, drawn out to a thread, and the lamp sealed off.

It remains now to test its efficiency, that is to say, the amount of light emitted for a given electrical power. A lamp may be said to have a very good efficiency if it yields one candle-power in return for 3·5 watts, so that an average 16 candle power lamp should absorb 56 watts.

The vacuum is usually tested by means of an induction coil; one method is to fuse two platinum wires into a glass tube leading to the lamp, and simultaneously exhausted with it, and to connect these wires to the terminals of the secondary coil. The distance between the ends of the platinum wires inside the tube is so adjusted that when the required degree of exhaustion is attained, the spark passes through the air outside the tube, in preference to traversing the vacuous space between the platinum points. Another method applicable to the finished lamp is to connect one end of the secondary to the filament, and the other to a loop wound outside the bulb, the quality of the vacuum being determined by the relative feebleness of the discharge which takes place between the filament and the bulb. It should be observed that, in a badly exhausted lamp, not only does the filament 'burn,' that is oxidise, but it also requires a greater amount of heat to raise and maintain its temperature at the required point, owing to the fact that the air particles carry a portion of the heat away by convection.

The 'life' of an incandescent lamp or the number of hours that it can maintain illumination varies considerably. Some filaments fracture in a few hours, while others will last for years, and we have seen one which had been burning steadily for at least 8,000 hours, and at a good efficiency. It will be obvious that the life of the filament must in a great measure depend upon the strength of the current which is sent through it. If a comparatively feeble current is employed the lamp will last much longer than it would with an abnormally powerful one. On the other hand, the luminosity increases much more rapidly than the current strength, so that the question really resolves itself into one of comparative expense. A lamp that is burning low yields a much lower efficiency, but lasts longer, than one of the same type which is brilliantly illuminated; but it may be accepted, generally, that it is more economical to run lamps at a high than at a low efficiency.

The filament of the Edison lamp, which is, however, rarely used now, is made from bamboo, which is carefully cut into very fine strips of the required length, provided with little enlargements at the extremities to facilitate the fixing to the platinum wires which are fused through the bulb.

The carbonising and subsequent processes are similar in principle to those already described, the method of fixing the carbon to the platinum being, however, somewhat different. The flat ends of the carbon are mechanically gripped by the platinum, and the junction is made electrically perfect by a small coating of copper deposited electrolytically,—that is to say, the joint is connected to the negative pole of a battery and is then placed in a bath or vessel containing a solution of copper sulphate, in which is immersed a copper plate connected to the positive pole of the battery. As the current passes through the solution, copper particles are dissolved off the copper plate, and an equal number of particles precipitated upon the joint. Electrical continuity is in this way ensured, but during the subsequent working of the lamp there is a tendency towards the disintegration of the copper, which is sometimes deposited upon the inner surface of the bulb as a thin metallic film.

Such are the general features pertaining to the construction of the Swan and Edison lamps; but the commercial interests in them have been amalgamated, and the distinction between them is therefore less marked than formerly, the Edison lamp pure and simple being now obsolete in England.

For ordinary purposes the filaments of the Edison-Swan lamps are shaped either as single or double loops. There are, however, several ways in which connection is made between the lamp and the external circuit, involving a corresponding variety in the form of the lamp-holders.

Figs. 273 to 275 illustrate the methods more generally employed for connecting the filament to the external circuit. In one of the lamps, fig. 273, the outer ends of the platinum leading wires are simply bent into small loops, the class of holder used being provided with two spiral springs connected to the circuit leads. The free ends of the springs are passed through the lamp loops, the shoulder of the lamp fitting into the circular part of the brass strip, the straight portion of which is just long enough to keep the spirals extended and so to make good electrical connection.

FIG. 273.

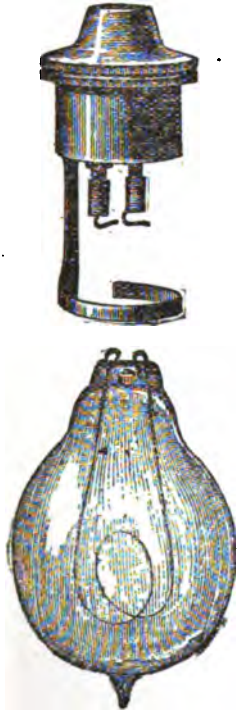
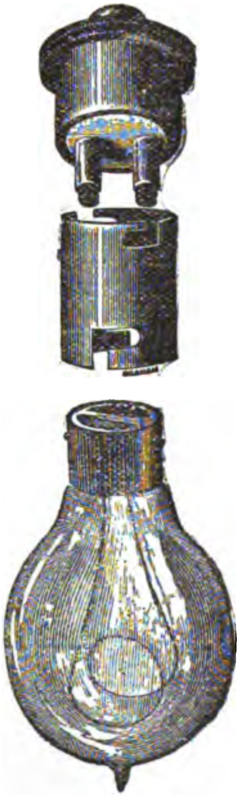


FIG. 274.



The top of the lamp shown in fig. 274 is provided with an insulated brass collar fixed with cement, the filament being connected to the two brass segments embedded in the cement. The collar has two small pins, which fit into the 'bayonet-joint' holder, which is shown in the figure, with its two parts separate. In twisting the lamp into the holder the segments make rubbing contact with the two spiral springs, which project a little from the guiding tubes. These spirals are connected to the circuit leads, and the lamp is thus thrown into circuit, by the mere act of fixing it in the holder.

FIG. 275.

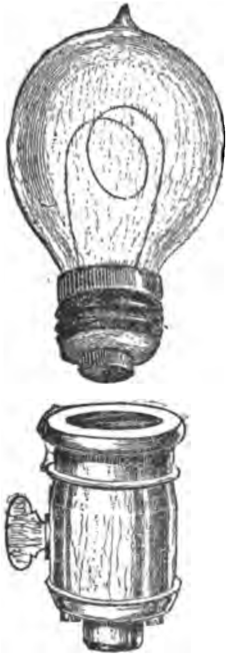
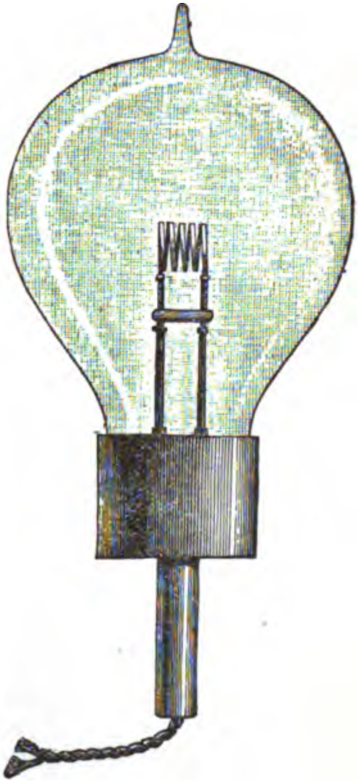


Fig. 275 illustrates the connection known as the Edison screw, in which one end of the filament is connected to the coarse screw thread, and the other to the insulated brass stud projecting from the bottom of the lamp. This affords another means of throwing the lamp in circuit by the act of placing it in its holder, which is provided with a corresponding brass screw thread, and a small brass disc mounted on a spring, which maintains contact with the stud on the lamp.

Lamp-holders are sometimes provided with small switches for making and breaking the lamp-circuit, the switch action being generally controlled by a tap handle similar to those used for gas-burners. In the Edison socket, as made by the Walsall Electric Co. (fig. 275), the tap carries a cam, which works against the curved edge of a brass strip, causing a to-and-fro movement of the spindle which, in the position for lighting, presses a brass spring against the stud on the bottom of the lamp. It releases with a snap action. Lamp-switches are, however, more generally independent, and fixed in convenient positions on the wall, &c., and one or two forms of them will be described in the following chapter.

Fig. 276 illustrates a form of lamp designed to overcome a difficulty experienced hitherto when using incandescent lamps for optical lanterns, as well as in other cases where the source of light should be small and approximate as nearly as possible to a point. The shape of the filament is that of a flattened spiral, forming a square grating constructed so that when fully incandescent it produces a square of intense luminosity, the light from which is wholly gathered up by a condensing lens in the focus of which the lamp is placed, and gives a perfectly uniform disc of light. This would not be the case if an ordinary incandescent lamp were used.

FIG. 276.



The lamp is mounted in a brass collar, with a shank to it, through which passes a flexible cord for leading the current to the lamp. A convenient holder is also made for the shank to fit into. It is provided with a set screw, by means of which the lamp may be varied in height or turned round; the holder is made with screw holes for screwing on to a block, or it may be soldered to the metal bottom of the lantern.

The lamp is made in two sizes (*a*) 35 to 55 volts, giving about 50 c. p. (*b*) 80 to 100 volts, giving about 100 c. p.

Incandescent lamps of the ordinary type are also made of high illuminating power, equal to that of 200, 500, and 1,000 candles. These lamps are suitable for interior lighting in public buildings and factories, and in other situations where a powerful and steady light is required.

In proportion to their actual c. p., these lamps are more economical to instal than groups of small incandescent lamps;

for example, the 200 c. p. lamp gives a light equal to 12 or 13 lamps of 16 c. p., but costs only twice as much as a 16 c. p. lamp, although the expenditure of energy per candle-power is in each case about the same.

These high c. p. lamps are fitted with strong brass terminals, and a special form of holder, which supports the lamp at the neck, takes the strain off the terminals, and can be readily adapted to any form of fitting, being provided with a screw thread of standard pitch—usually 1 inch male gas thread.

The following table supplied by the makers is interesting as showing the approximate E.M.F. and current required for the various classes of Edison-Swan lamps :—

1	candle-power	from about	3	volts &	·8	amperes	to about	8	volts &	·3	amperes
2½	,,	,,	5	,,	1·4	,,	,,	25	,,	·45	,,
5	,,	,,	5	,,	3	,,	,,	65	,,	·35	,,
8	,,	,,	10	,,	2·8	,,	,,	120	,,	·3	,,
16	,,	,,	15	,,	3·7	,,	,,	160	,,	·4	,,
25	,,	,,	40	,,	2·2	,,	,,	120	,,	·7	,,
32	,,	,,	50	,,	2·3	,,	,,	120	,,	·9	,,
50	,,	,,	50	,,	3·5	,,	,,	120	,,	1·4	,,
100	,,	,,	50	,,	7	,,	,,	120	,,	2·9	,,
Micro and Miniature Lamps		,,	3	,,	·8	,,	,,	8	,,	·3	,,

All lamps taking less than ·9 ampere are marked at 4 watts per candle, and all lamps taking more than ·9 ampere at 3·5 watts per candle. It is of course optional for consumers to run the lamps at higher efficiencies, if under the circumstances they consider that the higher efficiency compensates for the shorter life. Assuming an efficiency of 3·5 watts per candle, it follows that 746 watts, or one electrical horse-power, expended in the filaments would produce a light of 213 candle-power, an equivalent to that of thirteen 16 candle-power lamps. But the power developed by the dynamo is frittered down by the resistance of the leads, &c., so that, in practice, not more than ten 16 candle-power lamps can be maintained per horse-power generated.

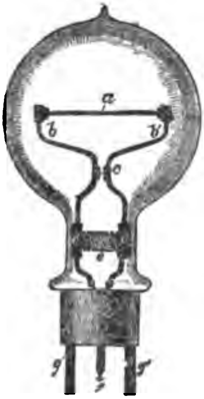
Lamps are sometimes silvered over one half of the bulb when the light is required to be reflected in one direction instead of being distributed all round. But in this case, the plane of the filament should always be placed in a line with the object it is sought to illuminate, as the light obtained from the lamp is always greater in that direction than in the direction at right angles to the plane of the filament. Artistic effect is also sought by colouring the bulbs to suit the surroundings, although this involves a loss of light, as certain of the rays are absorbed by the glass, the actual percentage so lost being governed by the particular colour employed. This absorption is altogether independent of the loss caused by the density or opacity of the material.

The Edison-Swan lamps are as a rule only made for parallel working, that is to say, they are all joined across the same pair of leads or mains, so that the current from the dynamo or other source divides between the various filaments. Of course it is possible to join two or more lamps in series, but under such circumstances the fracture of the filament in one lamp involves the extinguishing of the other lamp or lamps in series with it. If, therefore, all the lamps in a circuit were joined in series, the failure of one lamp would result in a total disconnection of the circuit. The parallel system has many advantages. There is no risk of receiving a serious shock on touching the mains, as the total potential difference is only that necessary for one lamp, which rarely exceeds 100 volts or thereabouts. If one of the branch leads should become broken, only the lamp on that branch will be thrown out of use. The means available for connecting the lamp to the supply wires are of the simplest description. The insulation of the mains is a matter of less difficulty than with high potential circuits.

On the other hand, the cost of the mains in a large installation is very considerable, for large conductors must be employed, otherwise their resistance would be so high as to cause a serious waste of electrical energy in overcoming that resistance. It needs also to be added that the maintenance of a constant potential difference throughout an extensive network of wires is a matter of some difficulty, a difficulty which does not attend series working.

The best lamp yet constructed for series or constant current working is probably that of Mr. Alexander Bernstein. The filament is composed of a slender carbon tube, made by carbonising a silk braid of fine texture, and it is remarkable that the fine threads composing the braid are distinctly discernible in the finished filament Fig. 277 illustrates the construction of the lamp in which the straight carbon tube or filament *a* is supported by pieces of iron wire *b* b_1, their lower extremities being connected to the short pieces of platinum fused through the bottom of the bulb. These wires, *b* b_1, are bent in such shape as to almost touch each other at *c*. They are also furnished with sleeves of insulating material *d* d_1, connected together by a spiral spring *e* which strives to draw them together. As long as the carbon is intact, its rigidity prevents contact between *b* and b_1 at *c*, but as soon as a flaw in the carbon appears the current commences to destroy it, and the spring *e* gradually draws the wires together, until a perfect contact is produced at *c*, and then a short-circuit is obtained inside the lamp. It will thus be seen that this is an excellent device for series working, for on the extinction of one lamp by the fracture of its carbon, the circuit for the other lamps is automatically completed.

FIG. 277.

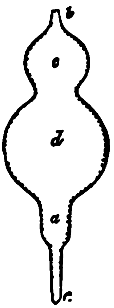


In a form of lamp now being introduced the spiral spring is dispensed with, a portion of one of the iron wires being hammered out flat, and a slight springiness imparted to it so that on the carbon being broken continuity is established at *c*.

The manufacture of the bulbs for 'loop' lamps is comparatively a simple matter, but with lamps having a rigid rod or tube such as the Bernstein, the case is very different. This will be evident when it is observed that the length of the carbon is considerably greater than the diameter of the neck of the bulb; with the ordinary bulb, the insertion of the mounted carbon would be a matter of impossibility.

The method of making the Bernstein bulb is very ingenious. Two bulbs, *e*, *d* (fig. 278), are first blown in a piece of glass tubing *b c*; the end *b* is then broken off, and the bulb *e* being heated it is worked into the form of an open cylinder. The carbon and the connecting wires, fixed in a glass stem, are then introduced through the large opening thus made, this opening being then closed so that only one bulb remains. The next operation is to weld a piece of small tubing to the top of this bulb, after which the small tube *c* at the bottom is broken off, and the stem with its connecting wires dropped through and fused into position. The next performance is to exhaust the lamp by way of the little tube fused on to the top, and that being completed, the bulb is sealed off and fixed into its socket.

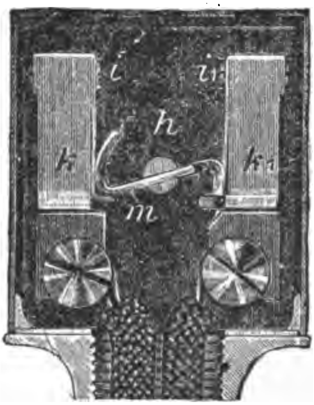
FIG. 278.



In order to prevent the interruption of the circuit by the removal of a lamp, its holder is constructed in such a way that the lamp can only be withdrawn from it if a short circuit has been made in the holder beforehand, and, furthermore, as this short circuit can only be broken after the lamp has been placed in position, it is not possible to disconnect the circuit at the holder.

This holder is shown full-size in figs. 279 and 280. A plate of insulating material, *h*, serves for the support of two metal sleeves, *i* and i^1, which are made suitable for the reception of the two square pins, *g* and g^1, of the lamp cap (fig. 277). For the purpose of obtaining a good contact between the pins and the sleeves, the outward side of each of the latter is cut away and replaced by two flat springs, *k* and k^1. The conducting wires are attached to the lower ends of the sleeves. The S-shaped piece, *m*, which can be turned by means of an external handle, serves the purpose of making a short circuit in the holder.

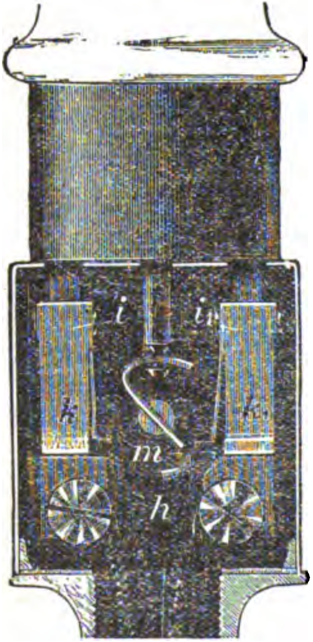
FIG. 279.



In fig. 279 the position of short circuit is indicated. For the purpose of obtaining a good contact between the piece *m* and the metal sleeves *i* and i^1, the latter are provided with two other flat springs, of which the one on the left side, near *k*, is bent at right angles at its lower end. The spring near k^1 carries at its lower end a square pin, which prevents the turning of the piece *m* in the other direction. The S-piece being thus fixed the circuit cannot be opened.

But if a lamp is placed into the holder, the two springs are slightly pressed outwards, and the square pin is forced out of the region of the motion of *m*; therefore *m* can be turned into the position shown in fig. 280, and in this case the current will pass through the lamp. It will be observed that the lamp cannot be moved out of the holder when the current is turned on, because the S-shaped piece *m* prevents the withdrawal of the lamp-cap by engaging with the peculiarly-shaped pin, *f*.

FIG. 280.



If it is desired to remove the lamp, the piece *m* must first be turned in the short-circuiting position shown in fig. 279.

The electro-motive force required by the lamp ranges from 4 to 15 volts according to the luminosity, which usually ranges from 10 to 50 candle-power. The normal current strength required is 1·0 amperes. On account of the small mass of carbon in the hollow filament, these lamps are very efficient, and it is claimed that with lamps of from 32 to 50 candle-power, the consumption of electrical energy is at the rate of only 2·75 watts per candle.

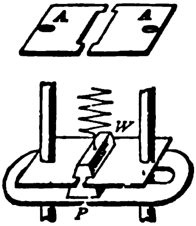
Lamps constructed after the principle of the Bernstein, that is to say for constant current, can also be joined up in circuit with ordinary arc lamps, which is, under some circumstances, a decided advantage.

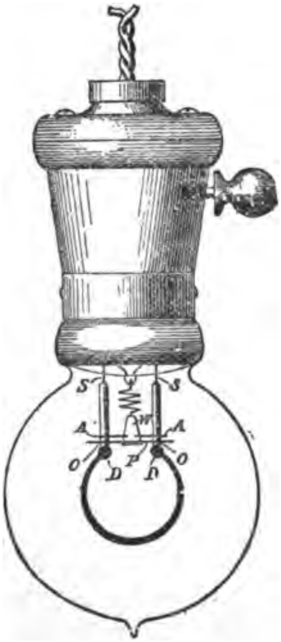
In cases where an arc lamp would give, at times, more light than is required and therefore waste energy, but where total darkness is undesirable, the Bernstein lamp is useful, as it can be joined, with the arc lamp, to a 'three-way' switch, by turning which either the arc or the incandescent lamp can be thrown in circuit, the current required for each being about the same.

When an ordinary incandescent lamp is used on a high potential circuit, a fracture of the filament sets up a small arc, which being sustained consumes the materials of the lamp and a disconnection is the result.

Mr. Edison in his 'Municipal' lamp has taken advantage of this feature to bring into circuit automatically a short-circuiting piece placed in the collar of the lamp. It is highly ingenious in design, and appears to answer when the fracture of the filament takes place during the time that the lamp is alight, but it is useless when the fracture takes place during the day, or at any time when the current is not passing, the E.M.F. being never sufficient to *initiate* an arc. Bernstein's plan is, under such circumstances, more satisfactory, although even here no provision is made against the mischievous stone-thrower or against any violent damage which might be done to the lamp. Accidents do happen which break the bulb and bend one or both of the iron wire supports and so prevent the short-circuiting at *c* (fig. 277) being effected.

FIG. 281.





Mr. A. A. Goldston has, however, devised a cut-out which acts promptly when the breakage is caused by any electrical or mechanical means. The device is illustrated in fig. 281, which shows the lamp, and an enlarged view of the cut-out. The leading-in wires, S S, are springy pieces of platinum and are connected to thicker pieces of iron wire, to whose lower ends, D D, the carbon loop is attached. Two small plates of German silver, A A, are rigidly fixed to the iron wires; below these is another plate, P, which carries a porcelain wedge, W, and is supported by a spiral spring, as shown. This plate has two slots, O O, through which the iron wires pass without touching. So long as the filament remains intact, it presses D D together and causes the wedge to be kept down by the pressure of A A. Should the filament be damaged, the tension at D D is released, the pressure of A A removed, and the spiral spring allowed to act. The wedge is then pulled up, and the plate P placed in contact with A A, thus short-circuiting the lamp.

There is another lamp, known as the Cruto, the filament of which is ingenious in construction and promised at one time to be successful. It consists of a fine carbon tube, made by depositing carbon from an atmosphere of coal-gas or other hydrocarbon, upon the surface of a platinum wire which is heated by an electric current. When sufficient carbon has been deposited, the current strength is augmented and the platinum wire fused out more or less perfectly.

Incandescent lamps are serviceable in a variety of ways. For domestic lighting they, although in most cases in England somewhat more expensive than gas, know no equal. They in no sense of the word vitiate the air, nor do they consume it; they have very little effect upon the temperature of a room; they are not injurious to furniture, books, or ceiling, and deposit no soot; they can be placed in curtains or other combustible materials without entailing any risk of fire; they are independent of air currents which cause flickering in any lamp where gas or oil is burned; they are exceedingly convenient and can be 'turned on' at any moment without necessitating the use of a match; the tap or switch for turning them on can be placed in any convenient position, such as on a door-post; and the lamps are incompetent to cause explosions, because the filament is destroyed immediately the bulb is broken. On the other hand, they consume a practically invariable amount of energy, for the light cannot be turned down without the introduction of a shunt, or of resistance, in which the energy which would otherwise be developed in the lamp is expended. They are, however, bad for street lighting unless of high candle-power, for most of the advantages which pertain to them when used in a house, disappear when they are taken into the street. The public look for a brilliant light and get only the equivalent of a good gas jet, and have to pay dearly for the luxury. They are exceedingly adaptable to the lighting of railway carriages. They know no equal for ship-lighting, their usual competitors in such cases being bad oil and worse lamps. In the case of passenger steamers expense is not of paramount importance; hence it is not to be wondered at that in this work incandescent electric lighting now reigns supreme. Incandescent lamps should prove of inestimable service in mines and in the bunkers of ships, where the chief difficulties to be contended with are want of portability and the risk of sparking between the broken ends of a wire or at switch contacts. These are trifling matters which must soon be conquered, and there is but little doubt, that before long the Davy and Geordie 'safety' lamps will be relegated to historical museums. There is a scope for incandescent lamps for the use of divers, and in many surgical examinations and operations, as well as for the microscope and the optical lantern.

In order to estimate the amount of light emitted by any luminous source, electric or otherwise, a large number of 'photometers' or light-measurers have been devised, but excellent as some of these may be in theory, they have, when applied practically, two serious defects. Measurement of every kind requires some unit or standard with which to compare the substance or force it is desired to measure; and it is pre-eminently essential that this unit or standard shall be fixed and invariable, and that it shall, without very much trouble, be reproducible. The majority of units comply more or less with these requirements; the one unit which does not, which is never fixed, but is always liable to variation, is the so-called unit of light. With us in England, the official unit is the 'candle-power,' which is assumed to be the light produced by a 'standard candle' weighing six to the pound and made to burn 120 grains of spermaceti wax per hour. The length of the candle varies slightly with different makers, ranging from 8½ to 9 inches measured from the shoulder, where the diameter is about 0·8 in., the diameter at the bottom increasing to 0·85 or 0·9 in.

In practical work a straight candle is selected and cut into two equal parts, which are subsequently used together on a short bar placed at right angles with the scale-bar of the photometer. The two flames give a more reliable, or better average result than a single one. Candles are lighted ten minutes before the commencement of testing so as to allow them to arrive at their normal rate of burning, which is shown when the wicks are slightly bent over and the tips glowing. In fixing them in position, the plane of curvature of one wick should be at right angles to the plane of curvature of the other. If the candles are used when the wicks are straight or when a little knob or rose of carbonised thread has formed at the tip, the tests will give erroneous results.

The special requirements of a standard flame are that the combustible must be of known and definite composition; the conditions of burning must be of a simple and definable character, and the nature of the combustible, as well as the conditions of burning, must be such that atmospheric changes may produce a minimum effect upon the light.

Now white spermaceti has a melting point of 109°, but a small quantity (varying from four to five per cent.) of beeswax with a melting point of 140° is usually added in order to prevent the crystallisation of the spermaceti. The spermaceti itself is not a definite chemical substance, its constituents varying considerably, whence it fails to answer the first requirement, for the consequence of the differences in the proportions of the natural and added constituents is that small variations are found to occur in the melting point.

The number and size of the threads in the wick, its chemical treatment, the closeness of the plaiting of the strands, and the degree of tightness with which the wick is stretched, are also conditions which affect the light of a sperm candle, yet they are all left undefined by the Acts of Parliament; and, in practice, manufacturers differ in regard to them.

Even were the candles made as exactly alike as possible there are other conditions of variation which cannot be eliminated. For instance, the light varies from moment to moment as the wick bends over, as the knob at the end of the wick accumulates or burns away, and as the cup fills or empties itself of melted sperm.

A number of experiments made by a committee appointed by the Board of Trade showed that while the candles from a single packet gave fairly concordant results, the average obtained by ten experiments with one packet differed as much as 15 per cent. from the average obtained by ten experiments with another packet. In 115 determinations a maximum variation was found between two pairs of candles of 22·7 per cent. in illuminating power. All these experiments were made by one observer, working with one apparatus and in the most uniform manner possible.

The method of taking the average of three consecutive candle determinations does not therefore serve to eliminate the errors of the candle standard, for the candles employed may be taken from a packet containing candles of a uniformly high or a uniformly low illuminating power.

Standard candles are greatly affected by slight differences of treatment, so that a candle which gives a certain amount of light in the hands of one operator, may give a widely different result when used by a second operator.

The extreme sensitiveness of standard candles to differences in treatment is shown by the following typical experiment. Four official gas examiners tested on the same day a specially stored sample of coal gas. They used the same photometer, and candles from one packet selected for the uniformity of the candles contained in it. The mean of two closely agreeing testings by one examiner gave the illuminating power of the coal gas as 16·5 candles, while the mean of two closely agreeing testings by another gave the illuminating power of the coal gas as 19 candles.

Mr. J. W. Dibdin has reported very adversely upon the standard candle. He found on one day that the average of the tests with candles made by one firm (A) showed the illuminating power of a certain gas flame to be equal to 15·8 candles, while candles manufactured by another firm (B) gave a value of 14·9 candles ; on another day candles A gave a value of 14·8 to a constant gas flame ; while candles B gave a value of only 12·9.

It can therefore be readily conceived that a total variation of

10 per cent. is almost a normal result, while far greater differences are of common occurrence.

Another cause of unreliability under certain conditions, is, that when the temperature of the testing room rises above the normal, the candles invariably give discordant results, sometimes indicating over 25 per cent. more than the known value of the comparison flame. The principal cause of variation is, however, the varying form and variable structure of the wick, which at one time had eighteen threads in each of its three strands, while at the present time the number has increased to twenty-one and twenty-three. Various improvements have been effected in the processes for 'drying' the spermaceti, or freeing it from oil, and the drier spermaceti now manufactured seems to require a wick containing more threads of cotton to raise it in the melted form and cause its combustion at the required rate of 120 grains per hour. But candles with thick wicks give less light than those whose wicks are thinner. Thus the effect of the improvement in the manufacture of spermaceti has been that standard candles give less light now than they gave ten years ago, and probably still less than they gave at an earlier date, when the average consumption of candles of six to the pound was 140 grains per hour.

A further very apparent objection is that the illuminating power is subject to fluctuations from minute to minute, owing to variations in the length and form of the wick, and to the filling and emptying of the cup of the candle, according to the movements of the surrounding air.

Sufficient has been said to make manifest the imperfections of the spermaceti candle as a standard.

One of the sources of error, viz., the irregular consumption of the spermaceti, can be to some extent allowed for by weighing the candle before and after the tests are made, the time of burning being also noted. If the consumption has not been at the exact rate of 120 grains per hour, the light emitted should be deemed proportionately different in intensity, and the measured intensity of the light as observed by the photometer, should be accordingly increased or diminished in the same proportion by a simple rule of three calculation. Thus if a lamp has been measured by the apparatus as giving a light of 17·6 candles, but the candles have been burning at an average rate of 116 instead of 120 grains, it follows that 120 : 116 :: 17·6 : x=17·01. A delicate balance is supplied with the better class of photometers, by means of which the rate of consumption can be readily ascertained.

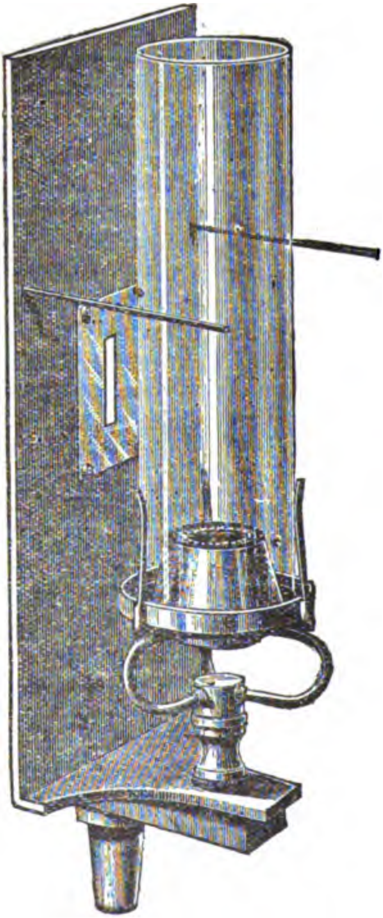
In Germany a standard paraffin candle is employed, but no better value can be attached to it than to the spermaceti candle.

The French sometimes use a stearine candle as a standard, but the actual French official standard is the 'Carcel' lamp, in which purified colza oil is consumed at the rate of 42 grammes per hour, and in which, of course, a wick is employed. The wick is cylindrical in shape and gives, therefore, an 'Argand' flame. It should be woven with 75 strands and weigh 3·6 grammes per decimetre of length. The chimney is 29 centimetres in height, its diameter being contracted at a short distance above the wick, from 47 to 34 millimetres. A good white light is produced, but from what has been said when discussing candles it will be evident, that for making exact tests, extreme care must be exercised in the manufacture and use of the lamp, and the combustibles. The chemical composition of the oil is liable to variation, and the simple fact that a wick is employed opens the way to a host of irregularities. It is, however, less affected by air-currents, &c., and is preferable to a candle. The standard Carcel is computed to be equal to about 9·5 standard spermaceti candles.

Several other attempts have been made to provide an efficient substitute for the standard candle, among others the lamp of Mr. Keates, in which sperm oil constitutes the fuel. This, however, involves the use of a wick, and the only suggested substitutes which may now be said to remain in the lists are the Methven screen and the Harcourt air-gas flame.

The 'screen' invented by Mr. John Methven is an exceedingly simple piece of apparatus. The instrument as now constructed by Messrs. Wright & Co. of Westminster is illustrated in fig. 282, and consists of an upright rectangular metallic plate or screen, having attached to its lower edge a horizontal flange or bracket, which supports a standard London Argand burner. This burner is supplied with gas through a plug or nosepiece projecting downwards below the flange. In the screen, above the level of the burner, there is a hole or slot which is covered by a thin silver plate, having a small vertical slot of such dimensions as to allow of the passage of just as much light as equals that afforded by two average standard sperm candles, when the gas consumed is sufficient to yield a flame three inches in height. It will be seen from the figure that a glass chimney is employed; it measures 6 inches high by 2 inches in diameter, the supply of gas necessary to produce the required flame being controlled by a tap, or in the better class of instrument by a micrometer cock capable of very fine adjustment. The two horizontal wires attached to the back of the screen, one on either side of the chimney, are placed at the requisite distance above the burner, and serve the purpose of determining when the prescribed flame length has been obtained. The apparatus is sometimes used with the richer pentane vapour as the illuminant (reference to which will be made presently). In such cases a second silver plate and slot is provided, of reduced dimensions, and furnished with a pair of horizontal wires $2\frac{1}{2}$ inches above the burner, to which height the flame must be adjusted.

FIG. 282.



The Methven screen has the advantage that it forms a reliable and practical standard, easy to manipulate and not likely to get out of order. Its simplicity of construction as well as of manipulation is self-evident, and its suitability for the required object has been demonstrated by Mr. F. W. Hartley, who made a number of lengthy series of tests with the apparatus, using slots of various dimensions. In one set of tests he found that with a 5 cubic feet per hour flame, of common coal gas of 14·02 candle-power, the difference in the photometric readings between a 3-inch Argand flame from the same gas and from cannel gas of 35·37 candle power, was only 0·7 per cent. These experiments tend to show that it is rather the height of the flame than the quality of the gas consumed which determines the luminosity, and this is a most important point, for it renders the standard virtually independent of any ordinary variations in the composition and lighting properties of the gas. A series of experiments was next made with standard candles which were employed to measure the light emitted by the common gas; the readings ranged from 13·24 to 14·588 candle-power, showing a difference of 1·348 candles, or 10·11 per cent. As these tests were made with gas supplied from the same holder, the result simply re-proves the utter unreliability of the standard candle. On the other hand, when the Methven screen was employed, the two kinds of gas being consumed in turn, the extreme difference was 0·83 per cent., and the mean difference 0·3 per cent. only.

While it is of course necessary that the height of the flame should be carefully adjusted, it is an important feature that the readings are not perceptibly affected by a variation of about one-tenth of an inch on either side of the prescribed height. The top of the flame should be as regular as possible, the burner of the best manufacture, and the chimney and screen scrupulously clean. As, however, it rarely happens that the top of the flame is absolutely regular, it is usual to so adjust the height that the extreme points extend about one-eighth of an inch above the horizontal wires. There is one other precaution, and that is, that the instrument should be allowed to get 'hot,' so as to arrive at the normal condition, before any reading is taken on the photometer. If this is neglected, erroneous results are almost inevitable, as the proportion of energy absorbed in heating the apparatus will be a varying quantity

However, this only entails a delay of about five minutes after the gas is lighted.

It is scarcely to be wondered at that a standard so nearly approaching perfect uniformity in its indications, and so simple in construction and manipulation, should have found considerable favour in the electrical industries, where it is almost exclusively employed. To put the matter in a few words, it is a practical piece of apparatus. As Parliament has not yet prescribed any particular luminosity for electric lamps, manufacturers of electrical apparatus, and those supplying electricity, are not, like gas companies, tied down to the sperm candle. Mr. Dibdin says that 'the adjustment of the height of the Methven flame is a matter of too little certainty, and lends itself to variations of readings in the hands of a biassed or careless operator.' Granting, however, that there may be some slight trouble in properly adjusting the flame, it is not a matter of great difficulty, and the Methven standard is hardly likely to suffer more than any other from careless manipulation. Mr. Dibdin, however, says when dealing with the pentane standard that 'the adjustment of the height of the flame is a matter of certainty.' He also urges that the employment of a chimney (by Mr. Methven) is a serious disadvantage, as the portion of glass exposed to the slot acts as a lens, and therefore affects the results. The objection is, however, hardly fair here, for the width of the strip of glass involved is so very small ($\frac{1}{4}$ in.) that it presents practically a plane surface.

In the standard suggested by Mr. A. Vernon Harcourt, and known as the air-gas or pentane standard, the combustible employed consists of a mixture of air with that portion of American petroleum which, after repeated rectifications, distils at a temperature not exceeding 50° C. This liquid consists almost entirely of pentane, its specific gravity at 15° C. ranging from 0·628 and 0·631.

To prepare the gas, Mr. Harcourt draws into the gasholder the required volume of air, chosen according to the capacity of the holder, and corrected for pressure, temperature, and tension of aqueous vapour ; then the corresponding proportion of pentane is poured into the gasholder from a measuring-flask or pipette. The proportion maintained between the air and the pentane, is one cubic foot of air to three cubic inches of pentane, measuring the liquid at or near 60° Fahr.; or, measuring both as gases, 20 volumes of air to 7 of pentane.

When the pentane is poured upon the water in the gasholder with about thrice its vapour-volume of air above, it volatilises rapidly and completely. A few minutes are sufficient for the volatilisation of the liquid, and a few hours suffice for perfect diffusion.

The opening in the burner has a diameter of a quarter of an inch, and is at the top of a cylindrical tube one inch in diameter and four inches long, the thickness of the disc forming the mouthpiece at the top of the tube being half an inch. With a burner of these dimensions the mixture of air and pentane gas yields as nearly as possible a flame 2½ inches in height, when the rate of consumption is 0·5 cubic foot per hour.

The adjustment of the pentane flame to give the unit light (equal to the mean of a long series of tests with standard candles), may be based upon the observations either of its height or of the rate of consumption, and may be effected either by adjusting the height of the flame till the tip of it touches, without passing, a horizontal platinum wire stretched over the burner at the desired height, or by adjusting the rate at which the pentane gas passes through a delicate meter. Experience of the two modes of adjustment has shown that it is both easier and more accurate to trust to the setting of the height of the flame, and to use the rate of consumption as a control only, without taking it into account in reckoning the illuminative value of the gas tested.

No material variation in the light given by the standard flame occurs when, the height of the flame having been adjusted accurately to 2½ inches, the observed rate of consumption does not exceed 0·52 or fall short of 0·48 cubic foot per hour. As a rule, the rate only varies within the narrower limits of 0·51 and 0·49.

A series of experiments performed to ascertain the effect of ariations in the proportion of air and pentane, demonstrated that an error or variation of 7 per cent. in the ratio of air to pentane causes a variation of 5 per cent. in the rate at which pentane gas needs to be passed through the meter to maintain a 2½-inch flame, and a difference of only 2 per cent., or ·03 candle, in the illuminative value assigned to the gas tested by comparison with it. But an error of even half this amount is rarely obtained in the actual preparation of pentane gas.

It is remarkable that only in 37 out of 468 testings, does the result of one testing differ from the mean result of the set of which it forms a part, by as much as 0·2 candle.

Tests were made with a variable height of flame, and the averages of ten observations made at the rate of one a minute, showed that with

Height of flame in inches . .	$2\frac{15}{32}$	$2\frac{1}{2}$	$2\frac{17}{32}$
The corresponding illuminating power was	99·25	100	100·75

Other experiments demonstrated that the illuminating power of the air-gas is but little affected by variations in the temperature of the room.

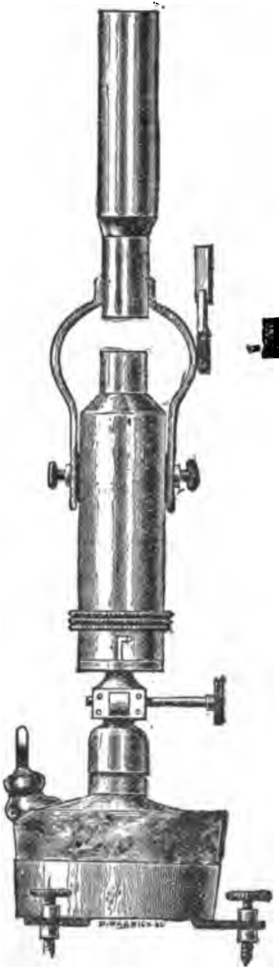
Mr. Dibdin is favourably impressed with the pentane standard, and in a report to the Board of Works, he recommended its early adoption.

Similarly the British Association Committee considered it to be reliable and convenient, fulfilling the conditions required in a standard of light, and they likewise urge the rejection of the Parliamentary candle as a standard of light, and the adoption of the pentane standard.

Mr. Harcourt has designed two or three portable pentane lamps, the latest and most convenient being that shown in fig. 283. In this case a wick is used, fitting loosely and moving freely within a tube which conducts heat downwards from the flame above, so as to give rise by evaporation to a quantity of pentane vapour sufficient to feed the flame, without the top of the wick being ever exposed to a temperature as high as that of boiling water.

The lamp (fig. 283) consists of a glass reservoir, with tubulure and stopper, of the form and size of a spirit lamp, mounted on a metal stand which rests on three levelling screws. The wick can be turned up and down in the usual manner by means of a double-toothed wheel, the spindle of which fits air-tight into the tube which supports it. The lower end of the wick (which is round and rather less than $\frac{1}{4}$ inch diameter) lies in the reservoir; the upper end is in a brass tube, about five inches in length, in which it can move up and down freely. The upper part of the tube is surrounded by a wider tube, about four inches in length and one inch in diameter; and the two tubes being joined together above and below by flat plates constitute the burner of the lamp. Around the burner is another cylinder open at both ends, of about two inches diameter, surmounted at the level of the top of the burner by a conical piece, terminating in a short tube whose diameter and length are about ¾ of an inch. Over this outer casing is a similar piece inverted, with the smaller tube below and the larger above. This second piece is connected with the first, the two being attached by two semicircular bands, so that the ends of the smaller tubes may be set at different distances apart, according to the amount of light which it is desired to obtain from the lamp. Through opposite sides of the upper tube, and above the ends of the connecting bands, are cut two narrow slots about ¼ of an inch in width, and ½ an inch in height. These are placed at such a height that whenever the tip of the flame is visible between them the light emitted is definite and constant. The adjustment of the light, which may be set at either half a candle, one candle, or a candle and a half, is effected by means of cylindrical brass blocks whose length has

FIG. 283.



been very carefully adjusted once for all. One of these blocks is placed upon the lower tube, and the upper tube is lowered until it presses gently against the block; the screws which fix the connecting bands are then tightened, and the block is withdrawn. Since the blocks are made of the same diameter as the tubes between which they are placed, they serve for setting these tubes truly on the same axis, as well as at the right interval apart.

The point, or rather the horizontal ring, from the nearest point of which measurements are to be made when the flame of the lamp is used as a photometric standard, is midway between the tubes which surround the flame, and at a distance of half the radius of these tubes from their axis, which is also the axis of the flame. This position is defined to the eye by giving to the curved connecting bands half the width of the tubes. The zero of the photometric scale lies in the plane which passes through the edges, on either side, of the connecting bands. To mark this plane by a solid surface, a rectangular strip of brass is provided, which can be fitted on one side into the centre of the edges of the connecting bands. A small plumb-line is also provided, by means of which the lamp can be set truly vertical, and a small mirror by means of which the photometrist can observe without changing his position whether the top of the flame is between the slots in the side of the chimney. The tests to which the lamp has been subjected demonstrate that it is fractionally less efficient than the pentane standard.

The 'battle of the standards,' as already mentioned, is confined to the types invented by Mr. Methven and Mr. Harcourt respectively. It is possible that the latter is slightly more accurate than the other, but it is less convenient, and is for that reason very rarely adopted in practice, while the Methven screen is very extensively used by gas as well as electrical engineers. The Methven screen is always ready, and measurements can be taken within a very few minutes of lighting the gas. On the other hand, the amount of heat evolved by the pentane flame is so small that a considerable time elapses before the burner has assumed its maximum temperature, or attained the normal rate of burning. Careful manipulation and experience are necessary in the process of manufacturing the pentane, an operation which of course takes time to perform. and which would therefore frequently preclude its use.

Under the circumstances it is perhaps as well that our laws change but slowly, and that the legal substitute for the universally condemned sperm candle has not yet been determined.

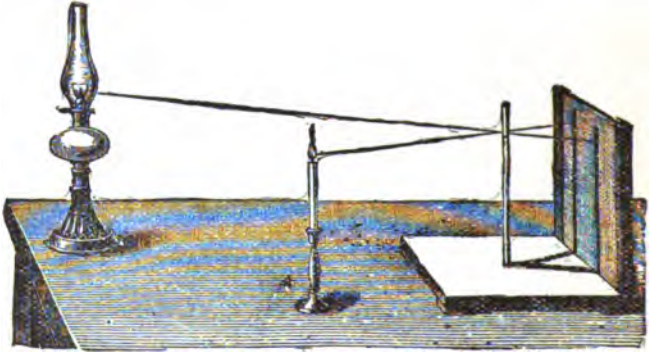
Supposing an absolutely reliable and permanent unit of luminosity to be available, we are still confronted by the second difficulty, viz., the want of a means of accurate measurement. Practical photometers are one and all simple comparison instruments, the light emitted by the standard and the source under test being compared simultaneously, and these comparisons must perforce be made by the eye. Unfortunately that organ is an untrustworthy piece of scientific apparatus and incapable of accurate discrimination. Its sensitiveness also varies considerably with the individual, so that the whole of any series of tests should be taken by the same experimenter, although even then there is some risk of personal error. Of course this difficulty is in some measure overcome by continued practice and attention.

All practical photometers are based upon the fundamental law that the intensity of illumination on a given surface varies inversely as the square of its distance from the source of light: and upon the fact that the distances of two independent sources of light can be so adjusted that their illumination of the given surface is equal. Then by measuring these distances the relative illuminating powers can be calculated.

The fundamental principle of the Rumford or 'shadow' photometer can perhaps be best illustrated by means of simple familiar apparatus such as that in fig. 284.

It consists of an upright ground-glass screen having fixed in front of it a small vertical rod. The standard light—in this case a candle—is placed at such a distance as to project a shadow of the rod upon the screen. The lamp, or other source, to be tested, is then brought into position so as to throw a second shadow close to that from the candle, and the exact position of the lamp so adjusted that the intensities of the shadows are as nearly alike as the observer can tell. The distances of the candle and the lamp from the ground-glass screen are then carefully measured and the comparative luminosities deduced from the law of inverse squares. For example, suppose the distance of the candle to be 12 inches, and that of the lamp $3\frac{1}{2}$ feet when the shadows are equal, then the luminosity is $1^2 : 3\frac{1}{2}^2$, that is to say, the light emitted by the lamp is $12\frac{1}{4}$ times as strong as that from the candle, and it may be called a $12\frac{1}{4}$ candle-power lamp. The comparative sensitiveness of the observer can be roughly estimated by moving the lamp to and fro for some distance, when, unless he is a professional photometrist, he will probably find that it is a very easy matter for the personal error to exceed 10 per cent.

FIG. 284.

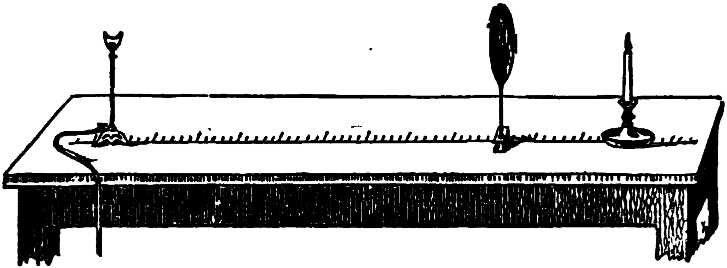


The principle underlying this instrument is simple, for it is evident that the shadow cast by the lamp is illuminated by the candle, while that cast by the candle is illuminated by the lamp, so that, if both shadows are reduced to the same degree of intensity, it can only be due to the effect of equal luminosities upon the surface of the screen derived from the two sources.

The Bunsen or, as it is often called, the grease-spot photometer is, especially for the beginner, an instrument by which more accurate results can be obtained; and it is the one most frequently employed. The principle of the apparatus is shown in fig. 285. A small screen of somewhat opaque paper is stretched on a metallic ring, which is mounted on a stand, movable along a graduated scale. In the earlier forms of this instrument, a semi-transparent grease spot was made in the centre of the disc by means of a little spermaceti dissolved in naphtha, but in the modern practical instrument, the whole of the paper, with the exception of a small central patch, is so saturated. To make an efficient screen is a matter of some difficulty, there being a particular thickness of spermaceti, which with each experimenter gives the best results.

The standard candle is fixed at one end of the scale, and the gas jet, or lamp (the luminosity of which is to be measured), at the other end of the scale, which should for convenience be divided into 100 or some multiple of 10 equal parts. The two luminants should be placed at such a height, that their centres are in a line with the centre of the screen, which can then be moved along the scale until the spot becomes invisible, and the whole of the surface appears to be uniformly lighted; or the screen and standard candle can be fixed, and the lamp under test moved along the scale to the required point.

FIG. 285.



The bottom of the stand carrying the screen (or lamp) should also be furnished with an index, and, the exact position of this index on the scale being noted, the relative distances of the two illuminants from the screen can be easily ascertained. Their luminosities can then be calculated by squaring these distances. The principle of this instrument is likewise simple. If a single light is held in front of the screen, the greased paper, which allows a portion of the light falling upon it to be transmitted through it, appears, when viewed from that side on which the light is placed, to be darker than the ungreased portion, which reflects liberally the rays falling upon it. If, on the other hand, the light is placed behind the screen, the grease spot or ring appears as a comparatively bright surface upon a dark ground, owing to the fact that the greased paper transmits a large portion of the light falling upon it, while the other part of the screen transmits scarcely any of the rays. When, therefore, the position of the screen between two sources of light is adjusted until the whole of the screen appears to be equally lighted, the two sides will be equally illuminated, the light transmitted by the greased paper being equal to that reflected from the ungreased paper. As a matter of fact, the grease spot is never capable of transmitting the whole of the light falling upon it, neither is the ungreased paper a perfect reflector nor absolutely opaque.

A beam of light falling upon a body is liable to be affected in three different ways; the rays may be transmitted, reflected, or absorbed. Bodies are called transparent when they transmit a large proportion of the rays, but all substances behave more or less as reflectors, for it is only by reflected light that non-luminous bodies become at all visible. All substances also, including even the best reflectors, absorb some of the rays, so that when a reflector is introduced into the measuring apparatus, some difficulty is experienced in estimating the amount of light. Professors Ayrton and Perry have invented a photometer, which, like their other productions, has a good scientific basis, and has been well considered in all its details. It was designed especially for electric lighting, and at a time when there was a great demand for means to measure the light from an arc lamp. It is based on the 'shadow' principle, but instead of moving the lamp away to a considerable distance in order to compare its light with that of the much feebler standard, a concave lens is employed, having the effect of scattering or dispersing the luminous rays, and projecting only a few of them upon the scale, whence it is known as a 'Dispersion' photometer. As the proportion thus utilised in casting the shadow can be readily determined, depending as it does upon the curvature and absorbing power of the glass, the direct result simply requires to be multiplied by a given constant to determine the relative luminosities. A plane mirror is employed to direct the rays upon the lens, the plane of the mirror being always adjusted to an angle of 45° with the incident beam so as to avoid the introduction of errors due to varying degrees of absorption for different angles of reflection. The mirror likewise carries a pointer moving over a graduated arc, by means of which the inclination of the incident beam to the horizontal can be indicated.

This instrument is no doubt very useful for laboratory purposes, but it is hardly one that could be placed in the hands of the average operator, for whom the necessary adjustments and calculations would be too intricate. This does not, however, detract from its value as a piece of scientific apparatus.

A beam of light has two other qualities besides that of illuminating a dark surface. It can easily be shown to possess more or less heat rays; also, that if certain compound substances are interposed in its path, chemical decomposition takes place. Were the three portions of the beam, viz., the thermal, the luminous, and the actinic or chemical rays, always united in the same proportions, we should have no difficulty in constructing a photometer accurate in its measurement and independent of the want of sensitiveness in the eye; for we could on the one hand use a thermometer, or a thermopile and a delicate galvanometer; or on the other hand a piece of sensitised paper such as is used in photography. But unfortunately the proportions vary considerably.

Tyndall has ascertained, as the result of a long series of carefully performed experiments, that the luminous rays from several sources of light bear but a small proportion to the obscure or non-luminous rays, the exact proportion of the former being from

An oil flame	3	per cent.
A gas flame	4	„
A white-hot spiral	4·6	„
An electric-arc light	10	„

The arc light appears here as the richest in luminous rays; it is also the richest in actinic rays, but the poorest in thermal rays. The various proportions differ, however, to some extent with different carbons, &c. The experiments demonstrate that, if either the thermal or the actinic rays are to be utilised for ascertaining the luminosities of electric lamps, they can only be compared together, or among themselves; they cannot be fairly compared with an oil or a gas flame.

In the practical measurement of electric lamps, modifications of the Bunsen photometer are, as we have indicated, generally employed. The form most frequently met with is the Letheby, which was designed for gas testing, and which therefore possesses many refinements unnecessary for electric light testing. The Bunsen disc is enclosed in a double conical tube or box to screen off extraneous rays of light, and small angular mirrors are placed opposite a pair of openings in the side of the tube, to facilitate observations of the two sides of the disc. The 'Universal' photometer, designed by the late Mr. Hartley, is simple, cheap, and efficient, and can be used for estimating the luminosities of arc or incandescent lamps, in a horizontal or in any other direction. It consists of a long narrow table, with two parallel grooves in the top; sliding in one of these are the Methven screen or other standard and the Bunsen disc, while in the other travels a scale, 21 inches in length, divided into tenths of an inch. For horizontal measurement, the lamp to be tested is fixed on an independent pillar at a known distance from the disc; if the lamp is suspended from the ceiling, an angle measurer is provided to facilitate the estimation of its actual distance.

It is the usual practice for an incandescent lamp to be carefully compared with some standard, such as the Methven screen. It is then in its turn employed as a standard of comparison for other similar lamps, requiring little attention, and affording a ready means of rapidly testing a large number of lamps. It is, however, only employed as a standard for a time, otherwise there would be some risk of error owing to a variation in the luminosity of the lamp. The method of testing arc lamps is somewhat similar. An incandescent lamp, after being standardised, is in this case, also, frequently employed as a standard, the arc lamp being placed on a scale at right angles with the photometer bar, which carries a mirror adjusted to an angle of 45° with the luminous beam, so as, in obedience to the law declaring that the angle of reflection is equal to the angle of incidence, to project the rays upon the greased disc, the quasi-standard being placed so as to illuminate the opposite side of the disc. The comparison is then made by adding the distance between the disc and the mirror to the distance between the mirror and the arc, and regarding this as the distance which has to be compared with that between the disc and the standard. A constant allowance has to be made for the absorption of the mirror, which for a certain angle varies with different samples of glass. It is obviously necessary that the arc should be so screened that none of the rays fall direct upon the disc, and that the angle of the mirror should be kept fixed. With a very powerful arc it would be possible to diminish the percentage of the rays falling upon the disc, by placing the lamp at a greater angle than that of 90° with the scale board or the axis of the disc. A fresh constant would then have to be employed, in accordance with the law that the intensity of illumination which is received obliquely is proportional to the cosine of the angle which the luminous rays make with the normal to the surface, allowance being also made for the increased loss due to absorption.

Where the space can be afforded, a photometer room should be provided, and fitted with opaque blinds, so that all extraneous rays can be excluded. The room, when candles or comparison flames are employed, should be free from draughts and vibrations.

CHAPTER XVII.

INSTALLATION EQUIPMENT, FITTINGS, ETC.

ONE of the most important details to be considered in connection with an electric light plant is the means to be adopted for transferring the energy from the generator to the lamp. In telegraphy it is a matter of secondary importance whether the line connecting the sending and the receiving stations measures 3,000 or 4,000 ohms in resistance, the number of primary cells employed for working the wire being simply varied according to this resistance. Consequently, unless a high-speed system of working is to be adopted, good iron wire answers every purpose, for it is a fairly good conductor, it is mechanically strong, and it is cheap. For high-speed working, copper is resorted to because the electromagnetic inertia of iron is too great to permit the necessary rapidity of current alternation.

In electric lighting, copper is always employed for the conductor. The current to be carried is usually very strong or heavy, and it is imperative that the loss of energy due to the resistance of the conductor should be brought down to the lowest practicable limit. Were iron to be employed, it would be necessary to give it six times the sectional area of the copper to obtain the same conductivity, and an iron wire or rod of such dimensions as it would be frequently necessary to employ would be too rigid for handling and bending. It would be necessary to make it in definite lengths and then to connect these lengths together at the place where they are to be used. But such a rod would also present very many additional difficulties in the way of insulation, and add considerably to the cost of that portion of the work. In fact, an insulated iron conductor would be considerably more expensive than one of copper offering the same resistance. The recently extended use of rapidly alternating currents is another reason against the employment of iron conductors.

It will be seen, from a study of the table given on p. 17, that the choice of materials for electrical conductors of any kind is really limited to the two metals above mentioned, viz., copper and iron; so that for electric lighting work we have no alternative but to use copper.

The table on the next page concerning the various sizes of copper wire generally employed gives some instructive details. It will be seen that most of these conductors are made up of a number of small wires stranded together, the chief objects being to impart greater flexibility and to reduce the risk of complete fracture.

Now as in overcoming the resistance of a conductor, electrical power is wasted, and as it costs money to develop electrical power, it is evident that in any commercial system such waste must be kept down to a minimum. This can be done by simply reducing the resistance, that is, by increasing the size of the conducting wires; but as this also is an expensive matter, care must be taken that the addition thus made to the expenditure in conductors is not so excessive as to more than counterbalance the cost of the power continually being saved. It has been laid down as a general rule, that, for the transmission of any given current, the size of the conductor most economical to employ is one offering such a resistance that the cost of the energy wasted per annum in heating the conductors, should be equal to the interest per annum on the original outlay upon them. Knowing the average current to be transmitted, it becomes easy to find the average electrical horse-power wasted in a conductor of any given resistance; but the cost of developing a horse-power depends upon many conditions, principally local, such as the cost of fuel, attendance, rental, repairs, prime cost and efficiency of the plant. And with regard to the conductors themselves, it must be remembered that it is not merely a question of the quantity and price of the copper employed, but also of the insulation and laying.

Most main conductors are, in England, placed underground, and as a rule the cost of laying considerably exceeds the actual cost of the wire.

Further, although the resistance of a wire one inch in diameter is only one-fourth of that of a wire half an inch in diameter, it does not cost anything like four times as much nor even twice as much to lay the thicker wire as it does to lay the thinner, for the

Number of wires in strand	Standard gauge of each wire	Diameter (in inches)		Equivalent to solid wire		Weight of Conductor per statute mile (lbs.)	Resistance at 60° Fahr. per mile (ohms)
		Of each single wire	Of the strand	Diameter (inches)	Area (square inches)		
1	22	·028	—	·028	·0006	12	72·52
1	21	·032	—	·032	·0008	16	55·53
1	20	·036	—	·036	·0010	21	43·87
1	19	·040	—	·040	·0012	26	35·53
1	18	·048	—	·048	·0018	37	24·68
1	17	·056	—	·056	·0024	50	18·13
1	16	·064	—	·064	·0032	65	13·88
1	15	·072	—	·072	·0040	83	10·97
1	14	·080	—	·080	·0050	102	8·884
1	13	·092	—	·092	·0066	135	6·718
1	12	·104	—	·104	·0085	173	5·257
1	11	·116	—	·116	·0105	215	4·225
1	10	·128	—	·128	·0128	262	3·470
1	9	·144	—	·144	·0162	332	2·742
1	8	·160	—	·160	·0201	409	2·221
3	25	·020	·042	·034	·0009	19	46·79
3	23	·024	·051	·042	·0014	28	32·50
3	22	·028	·059	·049	·0019	38	23·87
7	25	·020	·060	·053	·0022	45	20·01
7	23	·024	·072	·064	·0032	65	13·89
7	22	·028	·084	·075	·0044	89	10·20
7	21½	·030	·090	·080	·0050	102	8·893
7	20½	·033	·099	·088	·0061	124	7·342
7	20	·036	·108	·096	·0072	147	6·175
7	19	·040	·120	·107	·0089	182	5·002
7	18	·048	·144	·128	·0128	262	3·473
7	17	·056	·168	·149	·0174	356	2·552
7	16	·064	·192	·171	·0229	465	1·953
7	15	·072	·216	·192	·0289	589	1·543
7	14	·080	·240	·213	·0356	727	1·253
19	20	·036	·180	·159	·0198	402	2·261
19	19	·040	·200	·176	·0243	496	1·831
19	18	·048	·240	·211	·0349	715	1·271
19	17	·056	·280	·247	·0479	973	1·079
19	16	·064	·320	·282	·0624	1,270	·7154
19	15	·072	·360	·317	·0789	1,608	·5652
19	14	·080	·400	·352	·0973	1,985	·4579
19	13	·092	·460	·404	·1282	2,625	·3462
19	12	·104	·520	·458	·1647	3,354	·2709
37	16	·064	·448	·394	·1219	2,482	·3661
37	15	·072	·504	·443	·1541	3,142	·2892
37	14	·080	·560	·493	·1909	3,879	·2343
37	13	·092	·644	·566	·2516	5,130	·1772
37	12	·104	·728	·640	·3217	6,555	·1386
61	13	·092	·828	·728	·4162	8,477	·1072
61	12	·104	·936	·823	·5319	0,832	·0389

labour of removing and replacing the paving, earth, &c., would be almost the same in both cases. Again the insulation of the wire is an important and expensive item, which does not increase so rapidly as the resistance of a wire is reduced by an increase in its size; so that it does not by any means follow that a given reduction in resistance entails a proportionate increase in expense. It may be noticed incidentally, that when the diameter of a round conductor is doubled, although its sectional area and therefore its conductivity is increased four-fold, its surface is only doubled. Therefore if a current of four times the strength is passed through it, the heat developed will be four times as great (since power wasted $= C^2R$), while the surface at which radiation takes place has only been doubled. The temperature of the thicker wire will rise higher than that of the thinner one, when they carry currents in proportion to their conductivities.

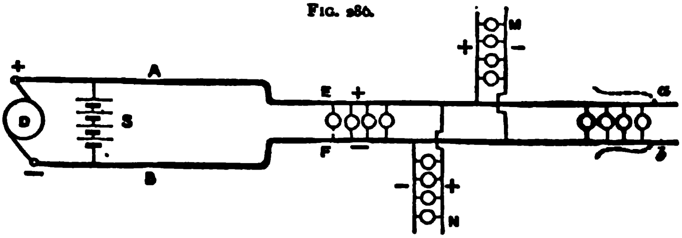
One advantage attending the use of bare conductors is the greater facility afforded by them for the radiation of heat as compared with covered conductors.

So many considerations, mostly special for every particular case, enter into the question of the best size and shape of the conductor consistent with strict economy, that we cannot discuss the matter fully here. But with regard to the reduction of resistance by the employment of high conductivity copper, it should be noticed that as the presence of a minute quantity of foreign matter causes such a great increase in the resistance of this metal, it is *always* economical to use the purest copper obtainable commercially.

In systems of distribution of electrical power by means of a constant current, the question is comparatively simple, as the current employed is not a heavy one, and has the same value at all times and in all parts of the circuit. The chief difficulty likely to arise is in providing for future extensions of the system when the potential difference which can be applied at the ends of the circuit is limited. The more interesting and more difficult problem consists in the supply of current to lamps, or other apparatus, at a constant potential; for then the main conductors have to carry a very heavy and variable current. The matter becomes more difficult if the lamps are distributed over a wide area, or are situated at a distance from the generating station. As has been pointed out in Chap. XIII., the power wasted may in such cases be reduced to a minimum, by transmitting it in the form of a small current at high pressure, and reducing the pressure at the required point, to a suitable value. But such a system has its disadvantages. Although the cost of the copper is vastly reduced, the high potential difference employed demands very efficient and expensive insulation, the engines and dynamos must always be kept running, and when very little power is being demanded the efficiency of the transformers and of the whole system falls to a low value. For even when the secondary circuit of a parallel transformer is disconnected, some current passes through the primary, and when only one or two lamps are joined up, the power appearing in the secondary may be but a comparatively small fraction of that absorbed by the primary. When the number of transformers is large, the total power wasted becomes considerable during the times when little or no light is required.

In the other method of distributing direct from the dynamo to a number of lamps all joined up in parallel, the chief problems to be faced are the heavy loss occurring in the mains and the difficulty of regulating the supply to each lamp.

FIG. 286.



Such an arrangement is indicated by the diagram in fig. 286, where D represents a dynamo capable of maintaining a constant potential difference at its terminals; A and B, the main leads from the machine to the nearest lamp; and E, F the continuation of those leads, between which the lamps are placed. Suppose there to be 100 lamps so joined in parallel, each requiring a current of half an ampere, and a potential difference at its extremities of 110 volts. The total current supplied by the dynamo with all the lamps in use would be 50 amperes, and this current would have to be carried by the main leads A and B. Supposing the resistance of A and B to be one-tenth of an ohm, the power wasted in overcoming this resistance would be 250 watts, and the consequent fall of potential 5 volts. Therefore the machine must develop at least 115 volts at its terminals in order to maintain 110 volts at the *nearest* lamp.

Now a further fall of potential would take place along the mains, E, F; suppose this to amount to 10 volts, then the pressure at the most distant lamp would only be 100 volts, while if this were raised to 110 by an increase at the dynamo, the nearest lamp would then be working at 120 volts. Even ignoring the waste of power, such a difference could not be permitted if similar lamps were used throughout the system, as some would be giving far above and others far below their normal candle-power.

It would, however, be practicable, but very inconvenient, to employ different types of lamp, placing those made to run at 110 volts at the end near the dynamo, and others constructed for 100 volts at the further end of the line, and so on. But even then, if the dynamo were perfectly regulating, the potential at the far end of the mains would rise considerably, when any number of the nearer or intermediate lamps were cut out of circuit.

Referring again to the figure, it will be observed that the mains at any one point only carry a current equal to that required by all the lamps beyond that point. Thus, while the portions, A, B, take the whole current, those portions between the last lamp and the last but one only carry half an ampere. The size of the mains might, therefore, be reduced by one hundredth as every lamp is passed, and the same density of current in the conductor be retained. This is equivalent to bunching 100 wires together to form the main, and taking out one of them at every lamp. If the 100 wires were separately insulated, that is to say, if a separate lead and return wire were used between the machine terminals and each lamp, the pressure at the ends of these leads would be constant; and since the resistance in each independent lamp circuit is also constant, the pressure at each lamp would be unaltered by any variation in the number thrown in circuit. This forms a means of maintaining a perfect regulation, although of course the actual pressure at the lamp would depend upon the resistance of its particular leads. Great as are the advantages of such a method, the expense would forbid its being employed in an installation extending over a large area. It will be seen, however, that with ordinary mains, if the resistance is sufficiently low to make the fall of potential very small, then the variation which would take place in the potential difference at the extreme end of the circuit becomes negligibly small. An extreme variation of 4 volts might be allowed, and then, by maintaining the normal pressure of 110 volts near the middle of the system, the nearest lamp would have but 112 volts and the furthest 108.

It is necessary to be able to observe in the engine-room the pressure existing at the far and near ends of the mains at any moment, so as to be able to keep one point as much below as the other is above the normal pressure; and this can be done by leading 'pilot-wires' from the mains at those points to a voltmeter placed at the generating station.

For instance, in fig. 286, a thin wire might be led from the point *a* and another from *b*, each to one terminal of the voltmeter, which would afford an indication of every variation at the extreme end of the mains. A second pair of pilot-wires might be led from the nearest lamp; or by leading one pair only, connected to the mains at the centre of the system, and keeping the potential there at 110 volts, a good average regulation might be maintained.

At an installation at Kensington Court, over two thousand 100-volt lamps are run in parallel, batteries of secondary cells being used in conjunction with the dynamos, for regulating, and assisting the machines to meet any large demand. Several circuits branch out from the engine-house, some of the lamps being 900 yards distant. At the extreme ends of all the mains, a pressure of 100 volts is maintained, while that at the nearest lamp does not exceed 102 volts. A pair of thin wires is led, as mentioned above, from the end of the mains, to a voltmeter in the engine-house, and when this instrument indicates a fall of potential (caused by the switching in of more lamps) the attendant immediately switches one or two secondary cells on to that pair of mains, in series with the existing cells, thus raising the pressure to the required value; the cells being of course cut out when the voltmeter indicates a rise of potential. The mains employed in this case consist partly of ordinary insulated cable, and partly of bare copper conductors stretched over porcelain insulators, in concreted channels.

Although on a simple parallel system of distribution, the arrangement is such that the whole of the lamps are connected in parallel between the two mains, it is evidently impracticable to join them directly across (as indicated in the case of the nearest and furthest lamps in fig. 286), when the mains are carried under the roadway. It is necessary to lead a wire from each main to every group of lamps, say to every house supplied, in the manner indicated at M, N. The higher potential mains are throughout marked +, and the lower potential, or return wires −. These subsidiary mains should be proportioned in size according to the number of lamps to be supplied by them.

It is not possible, however, to sufficiently reduce the resistance of a single pair of mains leading direct from the dynamo to maintain even approximately a constant pressure at all the lamps if they are distributed over a large area; a method of facilitating regulation in such a case, by the employment of subsidiary mains which feed the mains proper at certain points, but are not themselves tapped by lamp-circuits, will be described later on.

The method of employing a battery of secondary cells so as to assist in the regulation, or in the maintenance of a constant potential, is indicated in fig. 286, where S represents such a battery. The cells are joined in parallel with the dynamo, and are charged by it without any alteration in the connections being necessitated.

The interactions between the two generators—the dynamo and the battery—may be embraced under three heads. (*a*) When the E.M.F. of the battery is less than the potential difference at the dynamo terminals, the machine is supplying current to the lamps and at the same time charging the cells, the strength of the current passing through the cells depending upon the excess of the potential difference maintained by the machine over the E.M.F. of the cells. (*b*) When the E.M.F. of the cells becomes equal to the potential difference at the machine terminals both generators are equally active in feeding the lamp circuit. (*c*) When the E.M.F. of the cells rises above the normal—that is, above that potential difference which is required to be maintained at the terminals of the generators in order to maintain the right pressure at the lamps—then the battery not only feeds the lamp-circuit but raises the pressure at the machine terminals. This rarely happens, but the machine being shunt-wound, the effect is to increase the current through the field coils, giving a stronger field, which again tends to increase the E.M.F. developed. When the potential difference thus rises, it becomes necessary to cut out one or two cells to prevent the pressure rising sufficiently high to injure the lamps. A suitable switch is employed for this purpose, and the regulation effected by an attendant in accordance with the indications of the voltmeter.

It will be remembered that if the engine should break down, the cells would drive the shunt machine as a motor in the same direction; but an automatic cut-out should be provided to cut off the dynamo when the back-current from the cells exceeds a certain limit. A piece of apparatus capable of performing these operations was described in Chap. XIV.; it disconnects the machine when from any cause its potential difference falls below the E.M.F. of the cells. Under such circumstances the cells would be called upon, and should be able, to run even the whole of the lamps for a short period, or a portion of them for a considerable time.

It also becomes possible to economise power and the expense of attendance, by only running the machine during the hours when the demand is a maximum, allowing the cells to supply current to the few lamps required at other times.

It may occur to the student that a considerable saving in the mains would be effected by joining groups of lamps in series between the mains, all the groups being thus placed in parallel. This is so; for if the lamps were placed in sets of four in series, the potential difference between the mains would be four times that at the ends of one lamp, say 400 volts instead of 100. By this means the maximum current in the mains would be reduced to one-fourth, and the weight of copper correspondingly reduced, to give the same rate of loss of power.

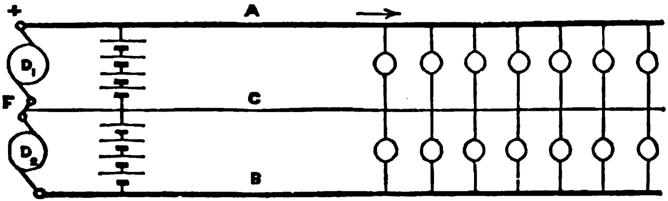
But some serious difficulties arise in connection with such a system; for instance, if the filament of one lamp in a set breaks, the other three lamps in that set are immediately extinguished; and if, to remedy this, the faulty lamp is merely short-circuited, the remaining three get too much current, and may also be damaged. Of course a device may be adopted to automatically switch in a second lamp, or to replace the broken one by a resistance equal to it; but the latter arrangement is undesirable on account of the waste of power: and in either case the extra fittings cause additional trouble and expense.

The same objection arises in the ordinary case of switching out one of a batch of lamps.

But even if the lamps are joined in sets of only two in series, a considerable saving is effected; and a method by which this can be done without introducing any of the difficulties referred to is indicated by the diagram in fig. 287. It is known as the 'three-wire system.'

Two equal dynamos, D_1, D_2, are joined in series, and connected to the mains, A, B, in the ordinary manner. That is to say, the positive terminal of D_1 is joined to the positive main, A, and the negative terminal of D_2 to the main, B, while the negative ter-

FIG. 287.



minal of D_1 is coupled to the positive of D_2. Suppose each machine to be capable of maintaining a potential difference of 110 volts: then when they are so joined in series they maintain the mains A and B at a difference of 220 volts. The lamps being joined, two in series, across the mains as indicated, the potential difference at the extremities of one of them is 110 volts. A third wire, C, much smaller than the mains, connects the junctions of the pairs of lamps, and is also joined to the junction of the dynamos.

Now when the number of lamps between A and C is the same as the number between B and C, the potential is the same at every point along the wire, C. Hence there is no tendency for any current to flow along the centre wire; it might, in fact, be cut at any point, or removed altogether, without in any way affecting the working of the system. But when the lamps on either side of it are made unequal in number, this state of balance no longer exists. Suppose a lamp between A and C to be switched out of circuit; then the resistance between A and C is greater, and therefore the fall of potential becomes greater, than between B and C. But the mains A and B are kept at approximately the same potential difference, and if the difference between A and C is increased, it can only be by the lowering of the potential of C. The effect of cutting out a lamp between A and C, then, will be to lower the potential of C near the point where the lamp is disconnected. But the potential at the point F remains unaltered; consequently this difference of potential establishes a current along the wire C, from the junction of the machines to the lamps. The strength is equal to that which flows through one lamp circuit; it may, in fact, be considered as the current which passes through the additional lamp between B and C. If a lamp between B and C is now switched out, balance is again restored, and no current passes along C. When the number between A and C is made the greater, the difference between those leads is lessened, that is, the potential of C near the lamps is raised This determines the flow of a current *from* the lamps to the junction of the machines along the centre wire. If the whole of one set of lamps were cut out, then the centre wire would have to carry the current supplied to all the lamps in the remaining set, in which case it would require to be as large as the other mains; in some cases the three mains are made equal, but it is usually possible to arrange the lamps so that this extreme case would never happen. Under favourable conditions the current which the centre wire has to carry, due to the difference in the number of lamps on either side of it, may be made comparatively small; and, consequently, the wire itself can be made much smaller than the mains proper.

It has been proposed to provide each lamp with a switch, by means of which it may be joined up between the centre wire and either main: the brighter light would be obtained from the main which already had the smaller number of lamps joined to it, and, consequently, the consumers, in their anxiety to obtain the best light, would assist in the regulation of the system.

Secondary cells may be employed in conjunction with the machines, as indicated in the diagram; two complete sets of cells are needed, their positive and negative terminals being connected to the mains and to the centre wire in the same manner as are the dynamo terminals.

A means of reducing the difficulty of maintaining a uniform potential difference along lengthy mains, is afforded by the use of independent conductors connecting various points in the circuit direct with the generating station, and these subsidiary leads are termed 'feeders. In some cases the mains themselves are not connected direct with the generator, the whole of the current being supplied to them at suitable points by way of the feeders. When the potential difference at or near the particular point to which a pair of feeders is connected, varies (as it does, with a change in the number of lamps in use), this difference is compensated for by correspondingly varying the pressure applied to the feeders, or by some other means varying the current passing through them. When, for instance, the number of lamps in circuit is increased, the pressure between the mains falls, and more current is required to be supplied by the feeders, and *vice versâ*.

It becomes necessary, therefore, to provide some means for promptly indicating, at the generating station, the variations of the potential difference at the points where the feeders join the mains. This is readily supplied by the employment of pilot wires, after the manner already described, these wires being simply connected to a voltmeter. When the instrument shows a fall of potential, the electrical pressure along the pair of feeders is augmented until the distant point is raised to the required standard. On the other hand, should the potential difference in the mains rise, then that on the feeders must be reduced. But economical adjustment in this way is somewhat difficult of attainment. It would, for example, be hardly practicable to use a separate dynamo for each pair of feeders, and to continually vary its output to suit the demand. It is preferable to use one or more dynamos connected to a pair of 'omnibus' bars, from which the whole of the feeders radiate. The potential difference between these bars must be kept equal to the maximum required. and the regulation can then be effected by inserting resistance or counter electro-motive force in the respective feeder circuits.

The insertion of resistance coils, however, while it is effectual and convenient, is wasteful. A more economical plan is to introduce a few secondary cells in each feeder, in such a manner that they oppose the feeding current. The effect is simply to oppose a counter E M.F. to the dynamo (since the cells have practically no resistance), but the potential difference is varied by the rather large steps of two volts at a time. In making any change both feeders must be similarly treated.

With the three-wire system it is obviously necessary to lead three feeding wires to each point and to connect pilot wires therefrom to two separate voltmeters.

The advantage of using several comparatively small machines joined in parallel, to supply the omnibus bars, is that a dynamo may be switched out and stopped when the demand for current falls.

When the feeders vary considerably in length, it may be advisable to divide them into two or even more groups according to their resistances, and supply the longer ones from a pair of bars maintained at a proportionately higher pressure than the similar bars supplying the shorter feeders.

Turning now to the methods of supporting, protecting, and insulating the conductors, we immediately observe that they naturally divide themselves into two classes, viz., overhead and underground.

The overhead system has the advantage of cheapness in construction, and it affords great facilities for inspection and repair, and for subsequent extensions. It is, therefore, generally employed where the local conditions are favourable, where the current employed is not so heavy as to require a very massive conductor, and where the potential difference is not excessively high. The system has, however, the disadvantage that the insulation is liable to considerable variation with weather changes. This can to a great extent be prevented by good construction, and the employment of properly designed 'insulators.' A series circuit, such as is used for arc or low resistance incandescent lamps, lends itself readily to the employment of overhead mains, since the current is in such cases constant and rarely exceeds ten amperes. A very small wire would be sufficient to carry such a current, but its size is really determined more by mechanical than electrical necessities.

For example, a wire of No. 12 B.W.G. would carry the current with safety, but a No. 8 or No. 10 is practically used on account of its greater strength. When the conductor is stranded, 7 No. 16's are employed, although 7 No. 20's would, from an electrical point of view, suffice. We ought perhaps to mention that all overhead bare conductors must be of hard-drawn copper in order to obtain the requisite mechanical strength. Ordinary pure copper is comparatively soft, and in a span of any considerable length cannot sustain its own weight; while in a gale, the wind pressure enormously increases the strain upon the wire.

Bare conductors are supported on insulators which are in turn supported by poles either of iron or wood according to local circumstances. One advantage pertaining to wood is that in the event of an insulator breaking, the conductor is still partially insulated from the earth, which would not be the case were an iron pole employed. Iron poles are obligatory for over-house work, or where appearance has to be taken into account. The best pole is that which consists of the complete trunk of a straight larch or other similar tree, which, after having been well seasoned, is thoroughly impregnated with good creosote. The natural life of the pole is enormously lengthened by this treatment. A convenient compromise is often effected by fixing a wooden top into an iron socket.

Insulators can be made from a variety of substances, but for climatic and other cogent reasons, white glazed porcelain is most frequently employed.

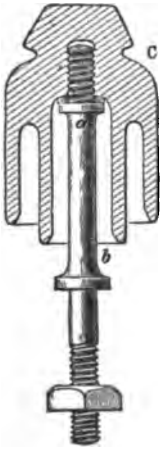
The chief requirements are hardness, smoothness, and imperviousness to moisture. Lacking either of these, the insulator is practically useless. It should be hard in order to resist abrasion by the wire; it should be smooth to prevent the accumulation of dust and dirt, to facilitate cleansing by rain, and to avoid the unnecessary wearing away of the conductor; and it should be impervious to moisture, in order that the rain should fall off instead of entering the pores of the substance and reduce, more or less permanently, its insulating properties.

Brown earthenware, made from clay, is, taking all things into consideration, also a good material. It is very hard, very durable, has a high resistance, and the glaze which it can take, although it is not so good and perfect as that on porcelain, is tolerably smooth and only allows the rain, unless the fall is very heavy, to gather in drops instead of forming a continuous film, as ebonite would do. Although porcelain offers a higher resistance than brown earthenware, the material varies very considerably, both in its constitution and in its manufacture. Some kinds are almost spongy, and as the glaze covers them there is no possible means of testing, except by breaking them. The glaze often cracks after a few months, and then, if the interior is at all porous, it absorbs moisture, and so in time lóses its insulating properties. When perfect it is undoubtedly the best insulator available.

It must further be pointed out that the insulator should be sufficiently strong to bear the strain imposed upon it by the wire. When all is quiet the insulator has simply to bear the weight of half the span of wire on either side of it, but when there is much wind the strain is increased considerably by the swaying of the wire.

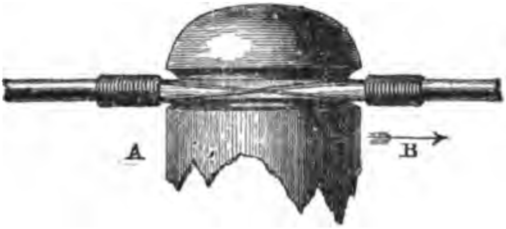
It is clear, then, that while the insulator must not be too large or heavy, it must be large and strong enough to sustain the weight it will be called upon to bear, and must have the maximum length, with the minimum area of surface between the wire and the iron pin or bolt supporting it.

FIG. 288.



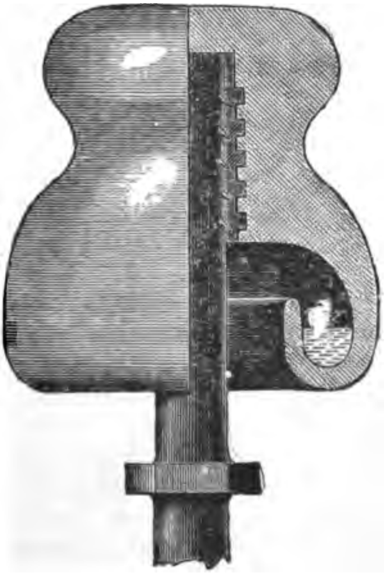
Considering the fact that the E.M.F. in an electric-lighting circuit is comparatively high, it is pre-eminently essential that the insulation should be of the best; parsimony in this respect is very likely to prove but the forerunner of disaster. When the line is straight, so that normally there is no lateral strain, and the conductor is not more than a quarter of an inch thick, the insulator illustrated in fig. 288 is suitable. It usually consists of a double 'cup' manufactured in one piece. The peculiarity about it is that it is provided with an open coarse screw thread by means of which it is screwed on to the bolt, permanently fixed to the arm or bracket on the pole. An india-rubber washer, placed at the bottom of the thread on the bolt allows the insulator to be screwed on tight without involving a risk of splitting it. The principal advantage pertaining to the use of a screw bolt is that in the event of fracture, the insulator itself can be replaced without necessitating the removal of the bolt. The method of fixing the wire to an insulator is illustrated in fig. 289. The conductor is laid in the groove, and a piece of thin binding wire, three or four feet long, is twisted several times round the conductor on one side, A, of the insulator; it is then wound round the insulator and is next twisted several times round the conductor on the other side, B, after which it is wound back again, round the insulator once more, and again over the conductor on the side A. Sometimes the bindings are soldered.

FIG. 289.



When high potential differences are employed, no trouble or expense should be spared to ensure the most thorough insulation possible. A form of insulator very largely employed for this purpose, especially in humid districts, where the risk of leakage is great, is illustrated in fig. 200. It is known as the 'fluid' insulator, from the fact that a quantity of oil is interposed in the path of leakage; the lip of the porcelain cup is bent up on the inner side to form a circular

FIG. 290.

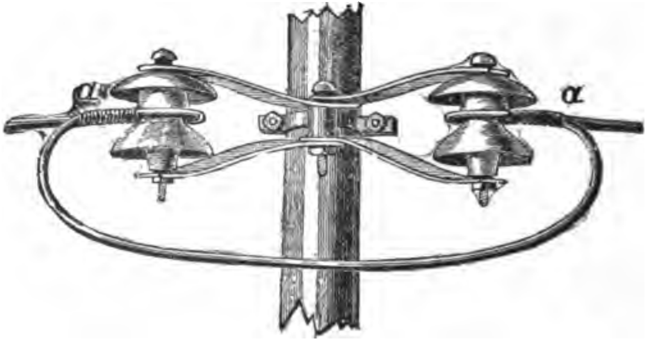


channel, in which the oil is placed by means of a small syphon capable of holding the required quantity. Experience has shown that very little dust accumulates in the channel, while the formation of a continuous film of moisture between the iron bolt and the conductor is entirely prevented.

These insulators are made in a great variety of shapes; in one case there is a separate oil cup supported on a pin which passes through the bolt. When necessary the pin can be removed, and the cup allowed to slide down the bolt, for the purpose of cleaning and refilling with oil; the cup can easily be placed in position again, and the syphon is therefore dispensed with.

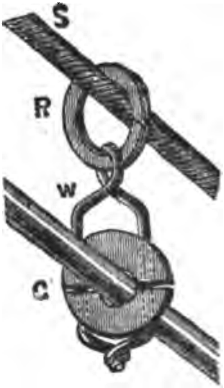
In fig. 291 is illustrated a form of insulator, known as the double shackle, which is useful on heavy lines. It consists of two insulators of porcelain of the shape shown; each has a stout iron bolt passing through it, and is supported by a pair of iron straps bolted to the pole, which, in the case illustrated, is of iron. The main wire is looped round the middle of each insulator, and fixed by a small binding wire wrapped on tightly. The straps of each insulator being independent of those supporting its neighbour, freedom of motion through a large angle is permitted, thus relieving the strain. The shackle should be employed in all cases where the wire makes an angle at the pole.

FIG. 291.



When an insulated aërial conductor is used, it cannot be attached to the insulators direct, because the friction which is always at work, would speedily cause the abrasion of the insulating material, and that at the very point where complete insulation is sought, viz., at the insulator itself. There is also the further difficulty that an ordinary covered cable has not sufficient tensile strength to enable it to support its own weight in a span of any considerable length. In such cases, a steel wire or rope S (fig. 292), is supported by shackle insulators, and carries a number of split steel rings, R. Engaging in each ring is a galvanized iron wire loop W, which supports a vulcanite chair C, and through which the cable is passed.

FIG. 292.

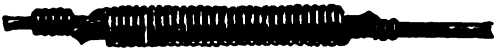


Sometimes the conductor is suspended midway between a pair of steel ropes by means of V-shaped pieces of iron wire, each piece being attached to three small reels of white porcelain threaded one on to the conductor and the others on the ropes.

One of the most important details in connection with the running of electrical conductors is that of jointing. The chief features which should pertain to a well-made joint are, that the electrical continuity should be fully maintained, that its mechanical strength should be at least equal to that of the conductor itself, that no free ends should be left on the finished joint, that it should be durable both electrically and mechanically, that it should be as compact as possible, and that with a covered wire the insulating coating should be made continuous and as uniform as possible.

For solid conductors up to a quarter of an inch or so in diameter, there is no better joint than that known as the 'Britannia' (fig. 293), which illustrates a joint of this kind made between two lengths of No. 8 B.W.G., bound with No. 16. The ends of the two conductors are carefully scraped and laid side by side for a distance of about two inches, about an inch or so at the extremity of each of them, having been previously bent up at

FIG. 293.



right angles to the axis of the wire. They are then wound over tightly, with several turns of thin binding wire. The binding is commenced on one of the wires only, round which four or five turns are wound; it is then continued as close as possible over the two wires, until the turned up portion of the second wire is reached, a few turns continued round the single wire completing the winding. The joint is finished by carefully and completely soldering it into one mass, and cutting off the then protruding ends of the wires, stray pieces of solder, &c. A joint made in this way approaches as nearly as possible to perfection, for its resistance is less than that of the other portions of the conductor, and its mechanical strength is much greater.

The method of jointing a covered stranded conductor is simple. Supposing it to be a 7-wire strand, the insulating covering is removed from each end for a distance of a few inches, care being taken to avoid nicking the copper. All the separate wires are then opened out and the centre wire on each of the ends to be joined, is cut off short. The two sets of wires are next brought end to end, and laced together, just as would happen when two hands are placed palm to palm, and the fingers of one hand placed between those of the other. This being done, the protruding ends of each conductor are wrapped closely round the other, the two wrappings being in opposite directions. The joint is then trimmed round with the pliers, and the whole well soldered together. The soldering is a more important matter than would at first sight appear, since the solder is relied upon to maintain the electrical continuity. Every care should therefore be taken that the copper surfaces are scraped clean before making the joint, that they are not handled more than is absolutely necessary, and that steps should be taken, as far as possible, to prevent oxidation. A very good plan is to use tinned wire, and to employ only resin as a flux. The conductor-joint having been completed, the insulating covering is then made good. If the material is gutta-percha, the conductor is wrapped with several layers of gutta-percha tissue which is softened by warming with a spirit lamp, and kneaded by the fingers to expel air bubbles. A few layers of gutta-percha strip are afterwards similarly applied, warmed and surfaced up with a warm metal tool, prepared tape being wound on to complete the joint. When the insulating material is india-rubber, strips of pure rubber are employed instead of gutta-percha.

When the conductors are to be laid underground, the chief difficulty to be contended with is the provision of efficient and durable insulation. The simplest method is to support the bare conductor by suitable insulators, after the manner described in Chapter XII. The distance between the insulators depends either upon the rigidity of the conductor, or upon the tension which it can withstand. Since every insulator is a point of leakage it is obviously necessary that their number should be reduced as far as possible.

In some electric lighting installations the bare conductors are supported by ordinary porcelain insulators fixed in a brickwork conduit with a concrete lining. In others, such as that in the Pall Mall district (London), in which the three-wire system is employed, the mains are carried in underground channels almost oblong in section, and made of cast-iron. At the junction of adjacent lengths a groove is formed in the sides of the channel, in which, at right angles to the length of the channel, is fitted a stout porcelain slab. The under edge of the slab is arched to allow the free flow of water along the bottom of the channel. The slab has also three deep vertical slots across the top, the centre one being somewhat narrower than the other two. Each conductor consists of a number of bare copper strips placed edgeways in the slots, and drawn tight enough to prevent contact laterally, while the depth of the strip is sufficient to prevent sagging. The centre conductor is formed of fewer strips than the outer mains; while the conductivity of all of them can readily be reduced beyond the points where branch circuits tap the mains, by reducing the number of strips. Long experience with underground chambers and channels, such as are employed for many other purposes, has shown that it is impossible to prevent the accumulation of water within them; hence the necessity for amply providing for the ready escape of water, that is to say, the conduit must be well drained. Electric light engineers have not yet had a sufficiently lengthy experience to enable them to appreciate fully the real difficulties which await them, such as those due to the corrosion of the iron and the falling of scale from the roof and sides of the channel; and to the incrustations and fungoid growths which manifest themselves in damp underground chambers. It would appear to be essential that good drainage should be supplemented by ample ventilation. Even were a conduit to be made water-tight there would still be sufficient moisture caused by condensation to oxidise the iron and make the surfaces of the insulators damp; although the passage of a heavy leakage current tends to dry the surface over which it passes.

It will, however, be evident that were the pipe containing the conductors filled with some good liquid insulating material, this accumulation of moisture with the attending disadvantages would be avoided. Paraffin oil is a liquid which has remarkably high insulating properties, and is, therefore, available for this purpose, but with a conduit constructed in the ordinary way, the quantity of oil required would be enormous. On account, however, of its high specific resistance, a thin film suffices to prevent leakage from one conductor to another, even though the potential difference between them be very great. The Brooks system is based upon this principle. So far the only application of it in this country has been to telegraphy, where, however, it has proved to be both reliable and economical under almost the worst possible conditions. A cable was made of forty cotton-covered copper wires of about No. 18 B.W.G. These were bound round with ordinary braid and drawn into a wrought-iron pipe of about 1¼ inch internal diameter, the length of the cable being about 1½ mile. The ends of the pipe by which the cable enters and leaves were sealed for a distance of two or three yards with paraffin wax, and paraffin oil was then supplied from a reservoir placed at one end at such a height as to be above the level of the other end. The joints in the pipe were made as secure as possible, but for some time the line was subject to a series of faults, caused by the leakage of the oil. The average loss may be put down at about thirty gallons a month, although from February to September 1889 only thirty six gallons had to be added. It is essential that the pipe should be not only water-tight, but also paraffin-tight The paraffin has, in fact, been known to exude through the iron itself, and stand in small beads on the outer surface; hence the necessity for using the best wrought-iron pipes. The chief objection to the system, the insulation-resistance of which is almost infinite, is that it affords few or no facilities for branching or T-ing.

The insulation-resistance being practically infinite, the system merits the serious attention of electric light and power-transmission engineers; but in cases where the mains are tapped at frequent intervals, the difficulty of making the branch connections will probably prove a serious drawback. In telegraph work, when two or more of the conductors get into contact, through the leakage of the oil, the fault is removed by refilling the reservoir, and so forcing more oil into the pipe: but a serious accident might arise from such a fault were the conductors to be employed for the transmission of heavy currents or currents of high potential difference. Some substance other than paraffin wax would also be required for sealing purposes, for were the conductors to become heated through a short-circuit, the wax would be melted and the oil allowed to escape.

Another method of insulating underground conductors, and the one generally adopted, is to cover the copper with some durable substance of high specific resistance, such as india rubber or gutta-percha.

In all such cases it is essential not only to efficiently insulate the conductor, but also to protect the insulating covering from deterioration by exposure, and to protect the whole cable from mechanical injury. When these points are very carefully attended to, an installation with insulated underground cables for the mains is very reliable, and gives little or no trouble in maintenance. But carelessness in manufacture or laying, or the use of inferior materials, gives rise to troublesome and most expensive repairs.

At present there is a tendency towards false economy in this matter. A thin covering of the insulating material is placed over the conductor, and when new and absolutely perfect the insulation may test higher than is actually essential in practice. But the slightest indentation or abrasion of the covering, such as may easily happen, and does happen, in handling during the process of laying, even if it does not quite expose the copper, leaves such a weak spot that the development of a 'fault' there, becomes only a question of time. The insulating covering, of whatever material, should be of reasonable thickness, not so much for the purpose of obtaining an extremely high initial insulation-resistance, as to ensure its maintenance at a fairly good value. Gutta-percha must be used with caution. If not exposed to light and air it is practically imperishable, and it may therefore be used with advantage under conditions which are at all similar to those obtaining in the case of a submarine telegraph cable; but it quickly cracks and perishes if employed in a dry, airy situation. In such cases india-rubber would be preferable; but for underground work pure and simple there is very little to choose between these two substances. With rubber, the copper requires to be tinned in order to protect it against the sulphur which rubber insulation usually contains. Gutta-percha, however, softens at a lower temperature than does india-rubber, and hence is more likely to allow the conductor to become decentralised when heated by the current.

These materials are the best available for insulating purposes, but they are expensive, and a large number of substitutes have been introduced. Some of them are fibrous in their constitution, and are impregnated with an insulating oil. Their specific resistances are lower than those of percha or rubber, but this is not a serious drawback provided the coating is sufficiently thick. They are not as a rule impervious to moisture, and require therefore a waterproof covering.

In some instances the temperature at which the compound softens is very high, whence the tendency to decentralisation is reduced.

Bitumen is a good insulating material, but it softens at a low temperature, and even at normal temperatures it is so plastic that the weight of the conductor itself would cause it to sink through the coating. The processes employed by the Callender Bitumen Co. overcome these objections. The material is vulcanised or treated with sulphur, with the result that, while retaining its high insulating properties, it becomes rigid and holds the wire permanently in position, even though the temperature of the conductor be considerably raised. The conductor is usually of stranded copper wire, tinned to protect it from the sulphur. It is first coated with a sheath of the vulcanised bitumen, applied under heavy pressure in one solid layer to the required thickness. This sheathing is then covered with cotton tape treated with bitumen, the number of layers ranging from one to five ; the cable is passed through a bath of hot compound after each serving of tape. The next process, for underground cables, is to apply a coating of jute yarn, and after another passage through the bath to cover it with hemp braid. Most of the cables are subjected to this treatment, the higher degrees of insulation being obtained by increasing the thickness of the dielectric—that is, of the vulcanised bitumen. For the smaller cables, such as are employed for indoor work, a layer of parchment tape is interposed between the conductor and the bitumen.

For important underground work the company has three distinct systems, the cables in all such cases being made as already described with the higher degree of insulation. In the first of these systems, a rectangular cast-iron trough is laid in a trench. The troughing is made in six-foot lengths, the thickness of the metal ranging from three- to five-sixteenths of an inch ; the internal dimensions vary according to the number and size of the cables, but in all cases the cable is kept at some considerable distance from the iron. One end of each length of the troughing fits into a socket made at the adjacent end of its neighbour. The two lengths are then bolted together and the joint sealed with bitumen. The cables are supported by a number of wooden bridges, generally placed at intervals of two feet. Each bridge before being placed in position is treated with bitumen, and has two or more vertical slots, according to the number of cables, each slot being rounded at the bottom, and just wide enough to fit the cable. A small quantity of natural or unvulcanised bitumen is run along the trough, and the bridges are imbedded in it before it solidifies. The cables are then laid in position in their respective slots, the dimensions of the wood being sufficient to keep them well clear of each other and of the iron. The trough is next filled up with pure bitumen and covered in with a one-inch layer of concrete, or an iron lid. It may be urged as an objection to this system that, the cables having been once laid, cannot in the event of a fault occurring be withdrawn ; but, on the other hand, the system permits of such good work being put in that the chances of a breakdown can be made very remote.

The second of these systems is designed to allow the cables, which are similar to those used in the previous case, to be withdrawn separately. The channelling consists of blocks of bituminous concrete made in six-foot lengths and jointed by a saddle-piece of the same material. The blocks are provided with longitudinal circular holes or 'ways,' varying in size and number according to the requirements, but only one cable is placed in each way. In most cases there are either two, three, or four ways, the diameters most frequently employed being 1½, 2, or 2½ inches.

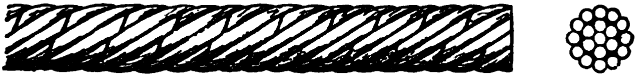
Draw-boxes are provided at convenient intervals, and the blocks having been fixed together in the trench, the cables are drawn in. This system has also the advantage that, should the cable-covering fail or give way, serious damage is prevented from the fact that the supporting material, *i.e.* the bituminous concrete, is a good insulator.

The 'saddle-pieces' embrace the sides and bottom of the blocks, and are provided with two grooves (one on either side of the joint), which are filled with bitumen.

In the third system the insulating material is fibrous in its constitution and is sheathed in lead. Over the conductor is wound a layer of parchment tape. Next to this is applied a rather thick layer of fine yarn, which has been dried at a very high temperature and then impregnated with boiling bitumen under pressure. The characteristic feature of this cable consists, in fact, in the processes adopted for the complete exclusion of moisture and air. Immediately after the impregnation is completed, and while the bitumen is still hot, the lead sheathing is put on direct with the aid of hydraulic pressure. The subsequent treatment varies with circumstances, but it is usually necessary to protect the lead from mechanical injury and the chemical effects of certain soils. For these purposes, the lead is passed through an asphalte bath and is then served with steel wire or ribbon, which is also covered with bitumenised tape or braid.

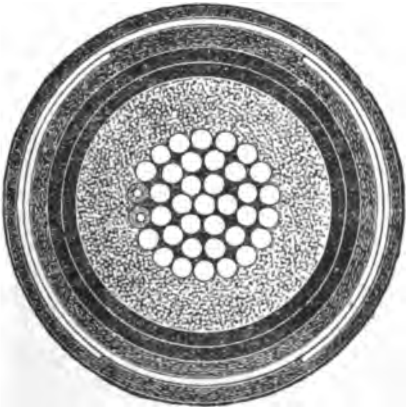
We have already described the method of making the splayed or long joint for stranded conductors, but in all Callender cables another form, known as the 'marriage' joint, is employed; a portion of the joint is illustrated in fig. 294. More skill and time are required to make this joint than are involved in the ordinary joint, but it has the advantage that the conductor is of uniform diameter throughout. It is also very strong and electrically good. Each strand is wound separately round the others and is cut to such a length that it abuts against the end of a strand from the other side of the joint. The end-to-end abutments occur at regular intervals, as can be gathered from the illustration; and the whole is well soldered. The covering is made good by pieces of materials identical with those already on the cables. In the case of the lead sheathing, an ordinary wiped joint might be employed, but owing to the uncertainty of always obtaining reliable plumbing work this method is not adopted. The cable ends are led through holes in the ends of a cast-iron joint-box, which after the ordinary insulating coating has been made good, is filled up with bitumen. A similar box, provided with three holes, is used at a T-joint.

FIG. 294.



A good type of electric lighting cable is manufactured by Messrs. Felten & Guilleaume, one form of which, designed for one of the mains on a three-wire circuit for incandescent lighting, is illustrated in fig. 295. The stranded core of high-conductivity copper is insulated with a layer of impregnated fibre, the thickness of which is about one-third the diameter of the conductor. Outside the fibre two coverings of lead are placed, as indicated by the black concentric circles in the figure. Over this is a layer of jute treated with an impervious

FIG. 295.



compound; and mechanical protection is afforded by a double sheathing of iron ribbon (shown white), the external covering being another serving of the impervious compound. This cable was constructed to be laid bare in a trench, and it contains the pilot wires which are necessary on an extensive parallel system. These two wires can be seen on the left of the conductor; they are of thin copper insulated with gutta-percha.

The lead sheathing is drawn on cold at an enormous pressure, and squeezes the fibre insulation into a solid mass. The two coatings of lead afford greater security against a small imperfection than could be obtained by a single coating with the same weight of metal.

When the cables are laid in an iron troughing, the iron sheathing is dispensed with, and the pilot wires are laid separately.

Wires inside a building must be efficiently protected to avoid damage or accident, as well as to maintain the insulation. A good plan is to run the wires along parallel grooves in a wood casing, as it is usually stipulated that the coverings of the two conductors should always be separated by an independent solid insulating substance. When it is necessary for one wire to cross another, a slip of wood is interposed. The casing can be made in a variety of forms, and if necessary can match the beading or cornice.

India-rubber covered with braided cotton forms about the best material for insulation for indoor work. Gutta-percha, for the reasons already enumerated, is less suitable, although its life can be considerably lengthened by protecting it from the atmosphere, which can be accomplished by carefully covering it with tarred tape.

We have already described certain pieces of measuring apparatus, but there are a number of other internal fittings which now claim attention.

The switch is a piece of apparatus which is in constant use, and for a variety of purposes, but chiefly to form a ready and expeditious means of making and breaking a circuit. The extension of the electric light has engendered a considerable development in the constructional details of such instruments, but in almost all cases the same general objects have been kept well in view. The forms of switch in use prior to 1878, from which time the revival of electric lighting may be said to date, are altogether inadequate for present purposes, mainly on account of the large currents which they are required to carry, and the high potential differences which may exist between the different portions of the apparatus.

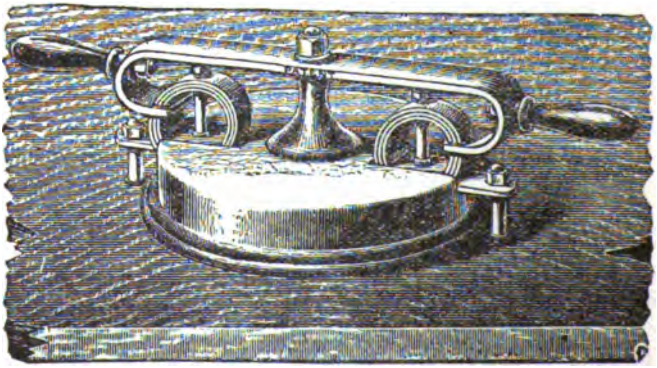
In order that a switch may be capable of efficiently performing its functions, its metallic parts must be sufficiently massive to carry the required current without heating or offering any appreciable resistance; the contact surfaces must for similar reasons be extensive; the moving contact piece must press firmly on to the fixed one; and simple striking contacts must give place to rubbing contacts, to avoid partial insulation through accumulation of dust and metallic oxide films. The circuit should not, when otherwise practicable, be completed through the axle upon which the rotating arm travels, unless a good independent rubbing contact between the axle and the bearing is provided, as dirt, oxide, &c., are liable to accumulate at the bearing surfaces, and in time impair the efficiency of the switch.

The switch should be so constructed that there is the minimum abrasion and wearing compatible with good and certain contact, and such parts as do wear away should be easily adjustable or cheaply renewable, so as to permit the re-establishment of good contact. In all cases, but more especially for currents of high E.M.F., the lever should be provided with a handle of insulating material. The terminals should never be so placed that in turning the handle there is any chance of the instrument being short-circuited by the operator's hand. When contact is broken the current (especially if the circuit contains any apparatus having considerable self-induction) sparks across the air space in the effort to continue its course, volatilising a portion of the metal surfaces. After such an 'arc' has been once established its maintenance is not a matter of great difficulty; and it is evident that such an arc is quite competent to start a serious fire, besides in any case damaging the switch contacts. It is advisable to provide a snap-action, so that the lever is set decidedly either on or off the fixed contact, the spring being so arranged that the lever is jerked quite away when it is turned almost out of contact. The actual sparking can in a great measure be prevented by causing the contact to be broken gradually instead of suddenly. The movable contact can be made to quickly travel over a set of fixed contacts, throwing more resistance in circuit at each step, until the current has become so low that it is incompetent to cause a serious spark. Such a device need only be used in special cases. The contact surfaces can easily be protected by arranging two carbon rods, placed end to end, as a shunt, and allowing the contact between the two carbons to be broken just after that between the metallic surfaces. The sparking then occurs at the carbon surfaces, and the rods can easily be renewed when necessary. The base of the instrument should be of some good insulating material, not liable to warping or appreciable expansion or contraction. Wood should therefore be used with caution.

What is required is a material which is non-inflammable, a good insulator, does not readily condense moisture, or facilitate the accumulation of dust and dirt. Slate is a good material if free from impurities, such as mineral streaks or veins ; glazed porcelain condenses moisture freely, and is brittle, the latter objection also applying to serpentine.

With these introductory remarks we can describe a few of the various forms of switch now in use. The 'ring' contact switch (fig. 296) is undoubtedly one of the best for carrying heavy currents. It is mounted on a slate base, each terminal clip consisting of a number of split brass rings placed inside one another, the contact being made by forcing the connecting bar into the gap

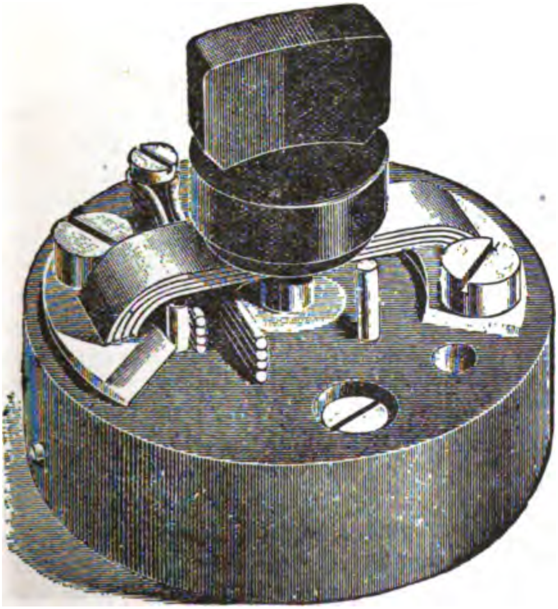
FIG. 296.



in the rings. This bar, which is a strip of stout brass with, in the particular form illustrated, the ends bent round, is provided with substantial wooden handles. As the contact surfaces wear away, the gap can be reduced by tightening up the bolt which it will be seen passes across the vertical diameter of the rings. Lugs cast on to the under side of the outer rings extend beyond the base, and are bolted to terminals underneath, or to tubular holders into which the main wires can be soldered. It will be seen that this form of switch practically answers every requirement, the safest possible connection being obtained, and the contact surfaces being self-cleaning. It is made to carry currents up to 1,000 amperes.

Messrs. Woodhouse & Rawson also make an excellent form of switch, shown in fig. 297. The switch bar consists of a number

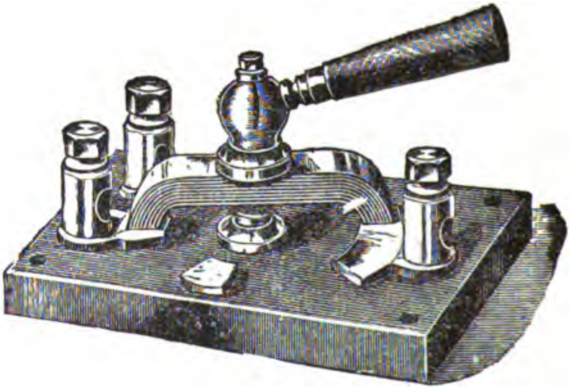
FIG. 297.



of—in this case four—bent strips of hard brass, which rub on to fixed blocks of a similar material. The edges of these blocks are bevelled, to prevent the bar jarring against them, and at the same time to allow it to slide fully on to them, although the pressure is considerable. The switch has a quick break, almost instantaneous, owing to the action of a bent spring, which is compounded of four steel wires, as shown in the figure. This spring presses against a projection from the axle, which is edge-on when the switch is in the position shown, but which with a small movement is presented obliquely to the spring, allowing the latter to jerk the arm away, clear of the contact blocks. These switches are provided with metal covers which are fixed by a bayonet joint.

Fig. 298 shows a modification which is made to carry up to

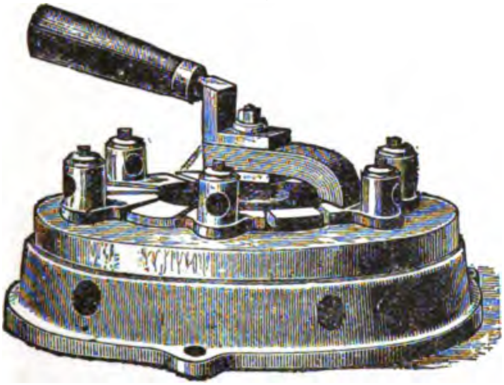
FIG. 298.



500 amperes. The contact arm or bar is made of several brass strips the extremities of which move over stout contact plates fixed to the slate base. This is a 'three-way' switch, the contact block, shown under the handle, being sufficiently large to allow the arm to complete the circuit from it to one or other of the two blocks near the opposite end of the arm. The circuit can also be completely disconnected, in which case the arm should be made to rest, in the intermediate position, on a pair of small plates, one of which can be seen in the front of the figure.

Fig. 299 illustrates a somewhat similar switch for enabling extra secondary cells to be placed in or out of circuit, one by one, during charge or discharge, as the arm is made to rotate. The short-circuiting of a cell is prevented by a coil of wire of suitable resistance mounted on a vulcanised fibre frame below the slate base, the whole switch being fixed on a hollow cast-iron frame,

FIG. 299.



perforated in several places to allow a free current of air to pass through it.

Another very useful form of switch is that in which the movable arm consists wholly or in part of thin flexible copper strips, screwed firmly into square tubes or sockets, and rubbing edgeways over solid brass or copper blocks. In one such switch the arm consists of a stiff flat spring terminating in square holders, in which the flexible brushes, composed of a great number of strips, are held by set screws. This type has the advantage that there is always an extensive contact surface, that adjustment is easy, that the brushes are comparatively inexpensive, and that they can be readily removed for cleaning or renewal.

In another switch of this type the arm consists of a large bundle of long flexible copper strips, passed through a rectangular hole in the axle and fixed firmly in position by screws. In this case the brushes rub against the inner vertical faces of the fixed blocks, instead of over the upper horizontal surface.

A switch of some kind is required in connection with every incandescent lamp or group of lamps, and of this class there is a vast number in use, many of them being simple forms of those already described. Fig. 300 shows one made by Messrs. Fowler, Lancaster & Co., in which the wires are connected to a pair of brass blocks which in their turn are connected to two long flat springs, whose free ends ride over projections on the wood or ebonite bar A B. Each of these projections consists of two parts, one being a non-conductor and the other brass. In the diagram the flat springs rest on the two insulating studs, but on pushing A B inwards towards the left, the springs ride over and make contact with the brass studs, which being but the ends of a short brass rod passing through A B, complete the circuit of the lamp.

FIG. 300

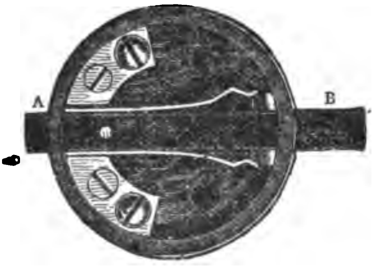


FIG. 301.

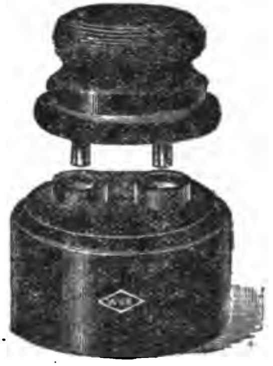


Fig. 301 illustrates a class of switch known as a wall socket, which is useful in cases where it is required to place a movable lamp in circuit at one or other of a number of positions, in such places as cellars, workshops, libraries, ship's bunkers, etc. The leads are joined to a pair of terminals in the lower block, which is permanently fixed in position. The upper or movable block carries the lamp, the terminals of which are connected to two split spring plugs, which can be pushed into the socket piece and so complete the circuit through the lamp.

Highly important as switches undoubtedly are in an electric light circuit, cut-outs can scarcely be said to be less so. The function of a cut-out is primarily to prevent damage being done to the apparatus, the leads, or the building in which they are placed, by means of an unduly strong current; and the way in which it affords this protection is by automatically disconnecting the circuit when the current from some cause, accidental or otherwise, exceeds a certain pre-determined limit.

There may be said to be two species of cut-outs, (*a*) those actuated by an electro-magnet, and (*b*) those consisting of a piece of wire or foil which melts or fuses with a current of definite strength.

A magnetic cut-out consists essentially of a coil of wire placed in the main circuit and provided with a movable core, or armature, to which is attached a strip of metal also forming a part of the main circuit. When the current rises above the prescribed strength, the coil attracts its core or armature with sufficient force to draw away the strip and break the main circuit. But it is necessary for the contact made by the strip with the ends of the main circuit to be very good and also frictionless, otherwise the pull required to break contact would be liable to vary. In the best instruments the two ends of the main circuit terminate in cups which are partly filled with mercury. A horse-shoe shaped copper rod is attached at its centre to the armature, and each leg dips into one of the mercury cups. The contact is thus reliable, but there is a chance of serious sparking occurring at the mercury surface when the contact is broken with a heavy current, especially if any large electro-magnet having considerable self-induction is included in the circuit. The advantages of such a cut-out are, that it can readily be adjusted to act with certainty with any given current, either by varying the tension of an antagonistic spring, or by altering the centre of gravity of the moving piece. It can also be arranged to automatically restore the connection when the current falls again to a safe value. Although this latter arrangement is not as a rule adopted, the apparatus can be immediately restored to its normal state by hand, when the cause of the rise in the current has been discovered and removed. It is manifest that the resistance of the apparatus must be kept extremely low to avoid serious loss of power. It requires a certain amount of attention and is expensive compared with the type next to be considered, viz. the simple fuse.

A fuse can be constructed so as to offer very little resistance, and therefore to absorb but little power. It must of course offer some resistance, since it is owing to the heat developed by the current in overcoming this resistance that the fuse is melted. Obviously a fuse made of a metal which has a low melting point requires comparatively little electrical energy to raise it to a state of fusion; and hence a fuse composed of such a metal may be made of lower resistance, and so absorb less power, than if a metal with a high melting point (such as platinum, 2,000° C.) were employed. In fact, with a well-designed fuse the chief cause of loss of power is likely to be in the careless connection of its extremities to the terminals of the main circuit.

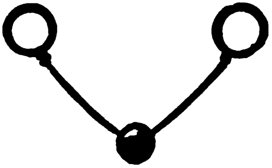
Such a cut-out has no working parts likely to get out of order or to need any attention, is very inexpensive, and, if properly designed, can be relied upon to act when the current reaches any particular strength, or at any rate within about 5 per cent. of it.

The fuse must be designed so as to break promptly and certainly, and manifestly it should not, if it can possibly be avoided, be allowed to get red-hot, otherwise the danger from fire becomes serious. The lower the temperature at which the metal employed melts, the less is the danger thus incurred. It must not be forgotten that good conductors of electricity are also good conductors of heat, and that therefore the terminal screws to which the fuse is attached conduct the heat rapidly away. This fact necessitates the fuse being made rather longer than would otherwise be the case; and while the terminals must be sufficiently massive to allow good and reliable connection, they should not be unnecessarily so.

It is almost superfluous to add that the metal employed should be durable, and not subject to change from any cause such as oxidation. Platinum fulfils this condition admirably, and yet it is a most unsuitable material for general work on account of the high temperature at which it melts. It is, in fact, easy to maintain it at a bright red heat for a considerable length of time. Tin, however, melts at 235° C.; it is very durable, only slightly oxidisable, and, taking all things into consideration, is undoubtedly the best metal for a fuse.

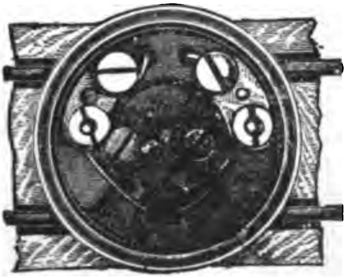
The best work in this field has been performed by Mr. A. C. Cockburn, whose fuse is illustrated in fig. 302. The wire is of pure tin, a leaden shot is cast on at the middle of the wire, and its extremities terminate in small contact rings. These rings are slipped over the terminal screws, and the nut being tightly screwed down reliable contact is ensured. The distance between the screws is such that the sag of the wire is about equal to that shown in the figure, and immediately the current becomes strong enough to develop sufficient heat to soften the wire, the weight of the leaden shot causes a prompt and decided break. The disconnection thus occurs long before the temperature is reached at which the metal would become red hot, and before dry wood would ignite or even char.

FIG. 302.



The cases in which these fuses are fixed are usually made of hard wood, or of slate or porcelain for the base with a brass cover attached by a bayonet joint. In some instances a wooden case lined with asbestos and fitted with a glass cover is employed, the great advantage being that the fuse can easily be inspected, so that when a number are in use it can quickly be ascertained which particular one it is that requires to be renewed. The rings at the ends of the wire enable the replacement to be effected with ease and rapidity, and they have the further advantage that they preclude any uncertainty as to the length of wire actually in use. Since the capacity of the terminal screws for conducting away the heat affects the result, the fuse should only be employed in the particular type of case for which it has been designed.

FIG. 303.



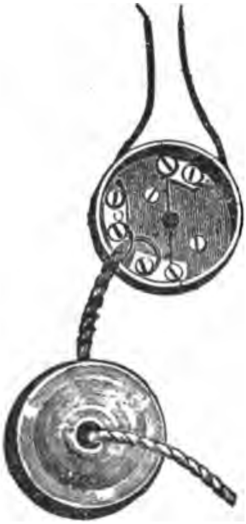
For heavy currents several comparatively small fuses are joined in parallel, instead of employing a massive wire, an arrangement which makes more certain the breaking of the fuses when the particular current strength is exceeded.

In fig. 303 is shown one of the simple fuses placed in position, the cover of the [illegible] brought up through holes in the slate base, one to each of two fixed brass strips, the fuse itself being connected to other terminal screws on the same strips. The case can if required be placed horizontally.

Many other types of cut-outs are in use, some consisting of wire, and others of thin foil of various metals, but that described is probably the best for general work, and is sufficiently inexpensive to allow of one being placed in circuit with every incandescent lamp in any installation.

An illustration of a method by which a cut-out may be applied to protect a single lamp is furnished by fig. 304, which shows a ceiling-rose, or a device for placing a lamp in circuit between a pair of leads carried along a ceiling, and suspending a lamp therefrom. The wires from the leads enter through holes in the back of the apparatus, and are connected each to a small brass block or strip, one of which is also connected to one lamp terminal and the other to one end of the safety fuse. The other end of the fuse and the other terminal of the lamp are joined to a third brass block. The flexible double wire by which the lamp is suspended is threaded through a hole in the centre of the cover, which screws on to the base.

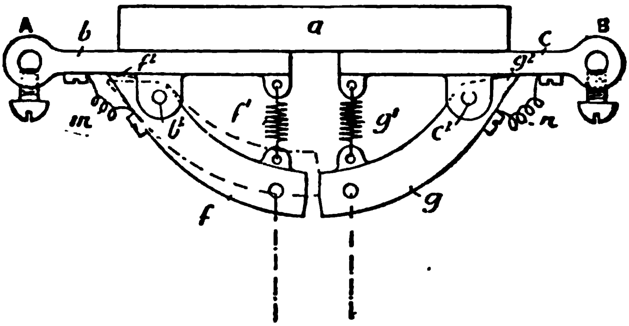
FIG. 304.



One possible objection to the use of a fuse is that when it does act under the influence of a too powerful current it is destroyed, breaks the circuit of the lamp or lamps, and must be replaced before the circuit is again available. It will be evident that such cut-outs must be cheap, placed in accessible situations, be easily replaceable, and be confined in an infusible or non-inflammable case.

The cut-outs which we have thus far described are intended as a safeguard against the maintenance of an excessive current, such more particularly applicable by the short-circuiting of a lamp, and they are working. When, however, a series circuit is fitted up, the danger to be guarded against is rather a disconnection than a short circuit, for should the filament of a single lamp, or any one of the conducting wires be broken, the current through the others will also be interrupted. We have already described (in the preceding chapter) a few protecting devices for the lamps themselves, but none capable of affording protection in the case of a complete smash of a lamp have been dealt with. Mr. A. A. Goldston has introduced a simple but ingenious contrivance for maintaining, under almost *all* circumstances, the continuity in a series circuit consisting of a number of suspended lamps. The device is illustrated in fig. 305, and is intended to short circuit the suspending wires of any lamp in the event of one or both of those wires breaking, or if from any other cause the weight on either of the wires is reduced.

FIG. 305.



A and B are the two main terminals which are attached to the brass pieces f^2 g^2 which are fixed on the insulating base *a*. The conducting spirals *m n* serve to connect the screws *b c* to another pair of screws on the contact-making levers *f g*. These levers are able to turn through a small angle on the pins b^2 c^2 and are supported by the spiral springs f^1 g^1. The wires by which the lamp is suspended are attached one to *f* and the other to *g*, the weight of the lamp sufficing to keep *f* and *g* apart. Should one of the wires, say that attached to *f*, break, the tension is reduced, and the corresponding spring f^1 is allowed to act, drawing *f* into the position indicated by the dotted lines and completing the circuit through the two pivoted levers direct. The device is also applied to arc lamps, and can be fitted in incandescent lampholders so as to maintain the circuit in the event of a disconnection at the platinum loops or in any portion of the holder. The spiral springs are in the actual apparatus provided with adjusting screws, by which their tension can be regulated so that were even the bulb broken this slight reduction of the weight would allow the springs to raise the levers. The arrangement effectually provides also for the case of a complete smash of the lamp, such as might destroy the short-circuiting device inside the lamp itself. Under ordinary circumstances a short-circuit between, or a fracture of either of, the suspending wires might initiate an arc, which would then probably travel up the wires and possibly start a fire. The device under notice prevents the maintenance of such an arc, because immediately the wire is fused and the weight removed the two conductors are cut out of circuit.

The apparatus is made in a variety of forms, but an advantage pertaining to the one illustrated is that the contact surfaces being vertical do not permit the accumulation of dust or dirt. The potential difference available in a series circuit is, however, sufficient to strike across even a considerable film of imperfectly conducting particles. It will be evident that to make this apparatus most efficient, it is better to use two separate instead of twisted conductors.

In a previous chapter we have described certain instruments called ammeters, which are capable of indicating the number of amperes of current flowing through them at any particular moment, but which are unable to measure the actual quantity of electricity passed through them during any given time. In just the same way a thermometer indicates the temperature at any moment, but gives no idea of the quantity of heat actually developed or absorbed. In the commercial distribution of electricity for lighting or other purposes, it is essential that a 'meter' should be provided which is capable of measuring and by some means recording the quantity of electricity supplied to any one consumer during say a month or three months. The unit quantity of electricity is the coulomb, that is the amount transferred by a current of one ampere during one second; hence an instrument such as that referred to might aptly be called a coulomb-meter.

The coulomb is, however, too small for electric lighting work. and it has been usual to employ as a unit the quantity of electricity transferred by a current one ampere in strength, during one hour. this unit being known as the 'ampere-hour.' If, for example, a secondary cell were allowed to maintain a current of 15 amperes for 2½ hours, the *quantity* of electricity obtained from the cell during that time would be $15 \times 2{\cdot}5 = 37{\cdot}5$ ampere-hours. But even this larger unit is somewhat small for the measurement of supply on an extensive scale. We have already mentioned the kilowatt as the practical unit of power, sometimes referred to as the Board of Trade unit of power. The Board of Trade unit, properly so-called, is a commercial unit of electrical energy, and is equal to that amount which is developed or absorbed by a current of 1,000 amperes at a pressure of one volt during one hour. It is therefore equal to 1,000 ampere-volt-hours.

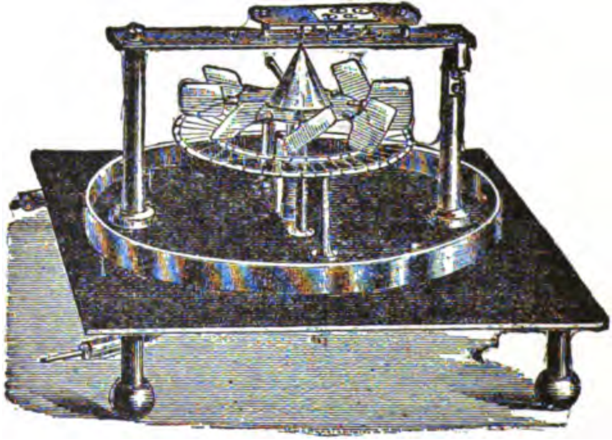
This Board of Trade unit is, then, the unit by which the electricity supplied is measured and charged. Under ordinary circumstances some piece of apparatus is introduced to indicate the number of ampere-hours supplied to the consumer's lamps, and this quantity multiplied by the pressure in volts and divided by 1,000 gives the number of Board of Trade units upon which the charge is based. But it is unfortunately far from easy to measure a quantity of electricity satisfactorily on a commercial scale. In fact the instrument most urgently needed in the electrical world at the present moment is a simple, reliable, and compact quantity meter.

Many efforts have been made to produce such an instrument, and although some practical forms have been brought into use, much yet remains to be done by the usual process of development.

The simplest in principle, and perhaps also the most interesting, is that devised by Professor Forbes. It is based upon the heating effect of the current; the instrument can therefore be made without any appreciable self-induction, and is consequently available for use with alternating currents.

The apparatus is illustrated in fig. 306. It consists of two concentric copper rings, supported at a little distance above the base and bridged across by a number of short fine wires. The current enters at one ring and leaves it by the other, passing through the whole of the fine wires in parallel, the resistance offered by the wires being about $\frac{1}{100}$th of an ohm. The quantity of heat developed in these wires affords the means of estimating the quantity of electricity which passes. When the wires become warm the heat is imparted to the adjacent air, which expands and rises, so that a continual upward current of air is maintained during the whole time that the current is flowing, the strength of the air-current varying of course with the extent to which the wires are heated. A small pillar carrying a steel needle point rises through the centre of the rings, and a thin paper cone with a ruby bearing at its apex rests on the needle point. The base of the paper cone is attached to a small horizontal mica disc, from the edge of which project eight arms made of pith, each carrying a very thin mica vane, inclined at an angle of 45° to the horizontal, and placed directly over the fine cross wires.

FIG. 306.



The ascending air currents caused by the passage of electricity strike against the under side of the vanes, and cause them and the paper cone to rotate; the stronger the current of electricity the more powerful are the air currents and the greater the number of revolutions in a given time. So that it is only necessary to add some device for recording the number of revolutions in order to estimate the quantity of current which has flowed.

The apex of the paper cone consists of a small aluminium cone (to which is attached the ruby bearing above referred to) and which also carries above the apex a small steel pinion, gearing into a train of wheels as shown in the figure. The train records the number of revolutions in the ordinary manner; but it will readily be apparent that since the force which causes the rotation is so feeble, the slightest friction would be inadmissible, and the whole of the moving parts must be extremely light and delicate. In fact, beautiful as the principle is, it is to be feared that it would be difficult to develop it into a thoroughly practical instrument.

A quantity meter also based upon an interesting principle, and which in spite of many difficulties is being brought into a practical form, is that of Mr. Ferranti. We know that a conductor when placed in a certain position in a magnetic field is urged to a new position in, or entirely out of, the field, immediately a current is passed through the conductor. If any portion of the conductor is movable independently of the remainder, we can move that portion only by sending all or nearly all of the current through it. A somewhat striking case is that of a liquid conductor such as acidulated water or mercury, for we can keep the liquid continually in motion by placing the containing vessel in a powerful field, and sending a current through the liquid. If the lines of force of the field and those emanating from that portion of the liquid which is carrying the current do not happen to coincide, then that portion will be urged to a new position just as a copper wire would be, its place being taken by more of the liquid, which undergoes a similar treatment.

In Mr. Ferranti's meter, which is based upon this principle, the liquid employed is the purest obtainable mercury. This is contained in a rather shallow circular vessel, above which is placed a solenoid fitted with a hollow iron core and a sheath, so disposed as to project a very powerful field vertically through the mercury. The current is led to the mercury at the centre of the vessel, and leaves it at the circumference, then passing through the magnetising solenoid.

Now the liquid conductor is urged to move in a direction at right angles to that in which the current is flowing through it, and also at right angles to the lines of force of the field. The direction of the current is radial, and supposing the lines of force to be projected vertically downward, the liquid will rotate in a right-handed direction as viewed from above. The force with which the mercury is urged to rotate is proportional to the strength of the current flowing through it and to the strength of the fixed field. This field might be kept constant; or by employing the same current to excite the solenoid, and never allowing the iron to approach the saturation point, the field may be made to vary with the current, when the force tending to produce rotation will be proportional to the square of the current.

The mercury in rotating carries with it a light delicate float, which is attached to the lower end of a light rod terminating at its upper extremity in a pinion which gears into a wheel forming part of the mechanism employed to indicate the number of revolutions made by the float. Of course the force acting is very small, and any appreciable friction would seriously affect the indications, but it appears probable that the difficulties will be overcome and the instrument brought into practical use.

The meter which, up to the present, has been most extensively employed is based upon the electrolytic properties of the current, and possesses the advantage that no delicate mechanism need be employed in connection with it. When a current is passed through a solution containing a metal, such as nitrate of silver or sulphate of copper, the solution is decomposed and the metal which it contained is deposited on the wire or strip of metal by which the current *leaves* the liquid. Such a wire or strip by which the current leaves or enters the liquid is called an electrode. Suppose, for example, a solution of nitrate of silver with silver electrodes to be employed, then pure silver would be deposited from the solution upon that electrode by which the current leaves. Moreover, an exactly equal quantity of silver would be dissolved from the other electrode; this might easily be proved by weighing before and after the passage of a current, for it would be found that the one had lost in weight just as much as the other had gained. The solution, then, remains as rich in metal as it was before the passage of the current; but if the electrode by which the current enters were made of carbon, or an unassailable metal like platinum, the solution would lose just as much metal as is deposited on the other electrode, the platinum not being dissolved at all.

It is a most important fact that the weight of metal deposited in this manner is exactly proportional to the quantity of electricity which has passed through the solution, irrespective, within wide limits, of the density of the solution, or the strength of the current at any part of the time. It follows that after having ascertained the weight of any metal which is deposited by a coulomb of electricity, or by an ampere-hour of electricity, we can always calculate exactly the quantity of electricity which has been transferred on any occasion, provided we find out what weight of that metal the current has deposited. Now the solutions which concern us most at present are nitrate of silver, sulphate of zinc, and sulphate of copper, and it has been found by experiment that one coulomb (or ampere-second) is capable of depositing from these solutions 1·118 milligramme of silver, 0·33696 milligramme of zinc, and 0·32709 milligramme of copper respectively. The ampere-hour, being 3,600 times greater than the coulomb, deposits 4024·8 milligrammes of silver, 1213·056 milligrammes of zinc, or 1177·524 milligrammes of copper. So long as the total quantity of current which passes is the same, it is immaterial whether the deposition is effected by a weak current flowing for a long time or a stronger current flowing for a correspondingly shorter time. Thus a current of half an ampere flowing for 48 hours will deposit the same weight of copper as a current of 16 amperes flowing for 1½ hour; in either case the total quantity of electricity is 24 ampere-hours. It is necessary, however, to take care that the surface of the electrode shall be ample, otherwise the metal is deposited so rapidly on a small surface that it becomes granular, and does not adhere.

Now suppose we take a vessel containing a solution of zinc-sulphate, and dip into the solution two zinc strips which have been accurately weighed. If, by suitable connections, we insert this arrangement in one of the main leads of an electric light circuit, zinc will be dissolved from one electrode, and an equal amount deposited on the other whenever a current is passing. If at the end of a month the plates are removed, carefully dried, and weighed again, the total amount of electricity which has during that period been supplied to the lamp circuit can be very accurately estimated. Slight impurities and local actions may in practice prevent the gain of the one being exactly equal to the loss of the other, but by weighing them both and taking the mean of the loss and gain, a more reliable result can be arrived at. As a rule, however, only the loss on the plate by which the current enters the cell, is taken as a measure of the quantity of current which has passed. Suppose this loss amounted to 1,213 grammes, then the quantity of electricity upon which to base the charge would be 1,000 ampere-hours.

The 'chemical' meter of Edison is constructed upon this principle, and it will be as well to point out a few of the possible sources of trouble and inaccuracy in the simple arrangement just mentioned, before describing the latest form of the meter.

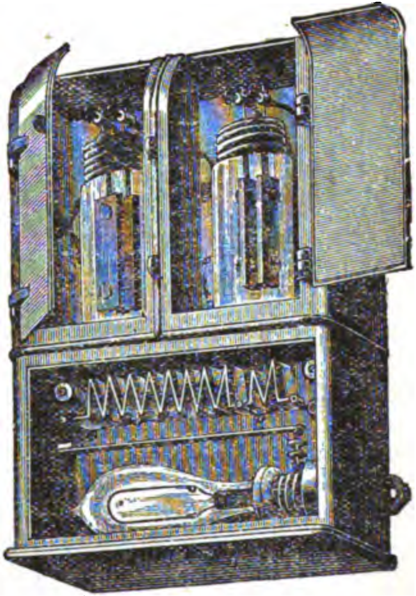
The cell offers some resistance to the passage of the current, depending upon the size of the plates and their distance apart; in order to allow it to be placed directly in an ordinary electric light main the size of the plates would have to be unduly large. It is necessary, therefore, to use the cell as a shunt, bridging over a short portion of the main circuit having a resistance equal to say $\frac{1}{999}$ of its own; in that case the meter measures $\frac{1}{1000}$ of the total current flowing.

But then temperature variations alter the resistances sufficiently to cause grave errors in the results. A rise in temperature, for instance, reduces the resistance of the liquid, but increases that of the portion of the main conductor which is shunted by the cell. Both these effects tend to cause an increase in the proportion of the current flowing through the meter, and such variations must in some way be compensated for.

Moreover, the temperature may fall low enough to freeze the liquid. Also since any external cause which cools the liquid or the shunted metallic conductor, or both, makes the meter register lower than it should do, care must be taken to so place these parts as to avoid leading the consumer into temptation. For similar reasons the terminals of a meter should never be exposed, nor any other facilities given for short-circuiting the apparatus.

The practical form of the Edison meter, as fitted for use in a simple circuit, and in which these difficulties are overcome, is illustrated in fig. 307. At the bottom of the case is an incandescent lamp, which is automatically thrown into circuit whenever the temperature approaches the freezing point, and so keeps the solution from freezing. Above the lamp is placed a stout zigzag strip of German silver, which is joined up in the main circuit. It offers but little resistance, and since its temperature coefficient is small, this resistance varies but slightly through ordinary changes. Above this strip two cells are placed, each containing two zinc plates immersed in a sulphate of zinc solution. The zinc is deposited at a definitely faster rate in one cell than in the other, and an additional check obtained by comparison of the two cells. The difference in the rate of deposition is effected by causing one cell to bridge a larger portion of the German silver strip than the other; the dividing terminal is seen in the figure at the end of the second bend from the right. The most important of the possible sources of error is that due to the temperature variation of the resistance of the liquid. This is compensated for and the resistance of the cell circuit kept constant in a very simple manner. When the temperature rises the resistance of the liquid *decreases*, but the resistance of a metal (copper for instance) *increases*. A spiral of copper

FIG. 307.



wire is joined in series with each cell, of such a resistance that with a given rise in temperature the resistance of the spiral increases by just so much as the resistance of the liquid is decreased. These spirals are placed behind the cells and are not visible in the figure.

In the smaller meters (and latterly in larger ones) only one cell is employed, the resistance of the German silver strip being about 0·003 ohm.

The meter is placed in the circuit of one of the mains feeding the group of lamps in which the electricity consumed is required to be measured.

For installations on the three-wire system two separate German silver strips with a cell or a pair of cells to each are provided, one strip being placed in each main.

The variation of the resistance of the German silver strip caused by temperature changes is not sufficient to introduce any great error. As a rule its resistance is $\frac{1}{999}$ that of the cells and compensating wire, so that the cell measures $\frac{1}{1000}$ of the total current passing through the main circuit. The plates are weighed once a month.

The method of throwing the heating lamp in circuit when the temperature falls too low is simple and ingenious. One terminal of the lamp is connected to one of the mains, and its other to a small contact stud placed just above the holder. Above this stud is another contact, carried at the end of a long straight compound metal strip, which is fixed at the other end (to the left in the figure) and connected to the other main. The strip is formed of two metals, which expand or contract unequally when the temperature is varied. Under ordinary circumstances the two contact studs are kept apart; but when the temperature falls, the compound strip bends or curls downward, and the adjustment is such that contact is made and the lamp thrown in circuit when the temperature approaches within two or three degrees of freezing point.

THE ELECTRIC TELEGRAPH.

History of Telegraphy.—Experiments in telegraphy were made as far back as the year 1753, when it was proposed to represent letters by combinations of sparks, etc.; but these were of little practical value before the discovery of the galvanic current.

The earliest proposal to use the transmission of electricity for the communication of signals appears in the *Scots' Magazine* for February, 1753, where a correspondent from Renfrew, who signs himself C. M., proposes several kinds of telegraphs acting by the attractive power of electricity, conveyed by a series of parallel wires, corresponding in number to the letters of the alphabet, and insulated by supports of glass or jewellers' cement at every twenty yards. Words were to be spelt by the electricity attracting letters, or by striking bells corresponding to letters. One Le Sage, of Geneva, in 1782, proposed to convey twenty-four insulated wires in a subterranean tube, and to indicate the letters of the alphabet by means of the attraction of light bodies. In 1811 Sömmerring suggested a similar application of voltaic electricity, chemical decomposition being the effect observed; and as, to a certain extent, he carried his suggestion into effect, he is sometimes regarded as the first who made a practical telegraph.

Samuel Thomas Sömmerring was born in 1755, at Thorn, studied medicine at Göttingen, and became Professor of Anatomy at Kassel. His many and valuable investigations give him a place among the first of German anatomists. Sömmerring was led by a suggestion of the Minister Montgelas to use the galvanic current in telegraphy in the following manner: When the Austrian troops crossed the Inn, 1809, and entered Bavaria, King Maximilian fled, in company with Montgelas, to Dillingen;

here he was surprised by the unexpected arrival of Napoleon. At this time Chappe's optical telegraph was used in France, and through it Napoleon had obtained the news of the crossing of the Austrians sooner than had been expected, and the consequence was that Munich, which had been taken on the 16th of April, was retaken by Napoleon on the 22d of April, so that Maximilian was able to return to his capital the same month. The prominent part which the method of signalling had played in this important event caused Montgelas to ask the Academy to lay proposals before him for a system of telegraphy. Although Montgelas can only have had in mind the optical telegraph, Sömmerring conceived the notion of making use of the electrolysis of water by the galvanic current for this purpose. His experiments commenced on July 8, 1809. On the 6th of August he telegraphed through a length of wire of 724 feet, and on the 18th of August through a wire 2,000 feet long. His apparatus

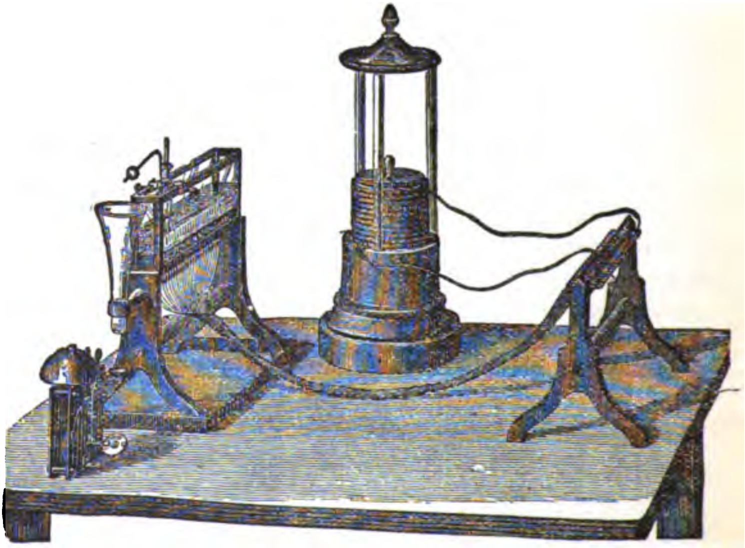


Fig. 308.—Sömmerring's Telegraph.

is shown in fig. 308. It contained twenty-seven wires for the twenty-five letters, together with stop and repeating signs. These wires were covered with an insulating substance, and twisted so as to form a cable. One end of each wire ended in a gold pin, which was cemented in the bottom of a rectangular flat glass box filled with water; the other end was connected with a frame containing twenty-seven connecting pivots, each of which was lettered. A voltaic pile, consisting of fifteen Brabant thalers, zinc discs, and felt impregnated with a solution of ordinary salt, was used as a battery. The poles of this battery ended in plugs, which were inserted in two holes of the pivots, and hydrogen and oxygen were then evolved at the corresponding gold pins, and by seeing at which pole the gas was produced the observer told which letter it was intended to signal. Sömmerring further combined with this apparatus an alarm, as shown in the figure. A spoon-shaped glass vessel, placed so as to catch the escaping H and O of two gold pins, was connected with an angular lever; the horizontal arm of the lever reaching out of the glass box loosely supported a leaden ball. When the evolution of gas commenced the spoon was raised, and the protruding arm of the lever was lowered, and the leaden ball allowed to fall through a glass funnel upon the lever of a clock, which made the bell ring. Sommerring's apparatus was never applied to practical use.

In 1819 the deviation of the magnetic needle through the action of an adjacent galvanic current became known, and Ampère, in 1820, and Fechner, in 1829, showed how to make use of this fact for telegraphic purposes. Ampère's plan was to use thirty needles and sixty wires; Fechner's, twenty-four needles and forty-eight wires; for at first it was supposed that there must be a separate needle for each letter or sign signalled; these proposals, however, came to no practical results.

Baron Schilling constructed an electro-magnetic telegraph in 1832 by making use of the multiplier devised by S. Ch. Schweigger; but the first electro-magnetic telegraph of which practical use was made was the telegraph constructed by Gauss and Weber at Göttingen in 1833, with a line of 3,000 feet.

Johann Carl Friedrich Gauss was born in 1777 at Braunschweig; he studied at Göttingen, and was a pupil of T. F. Pfaff. In 1807 he was appointed Professor and Director of the Observatory at Göttingen. Wilhelm Edward Weber was born in 1804 at Wittenberg. He studied at Halle, and published in 1825, jointly with his brother, Ernst Heinrich, his classical work, *Die Wellenlehre*. He was introduced to Gauss by A. von Humboldt, and through his influence obtained the post of Professor of Physics at Göttingen.

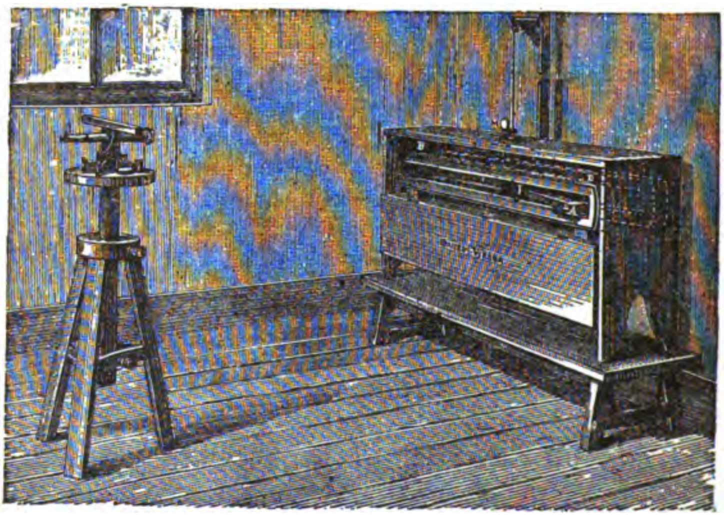


Fig. 309.—Gauss and Weber's Telegraph.

Their original apparatus was sent to the Exhibition at Paris in 1878, and has been described in *La Lumière Électrique* (vol. viii.) It is represented in fig. 309. B B is a galvanometer frame in which the magnet A of 1.21 metres in length is suspended by means of a silk thread, and carries a small mirror M. The sender consisted at first of a simple galvanic battery, for which the induction apparatus shown in fig. 310 was afterwards substituted. Two large magnets A, each weighing twenty-five pounds, were arranged vertically upon a frame, so that their north poles projected above the frame. The induction coil B was placed loosely about the middle of the magnets so that it could be moved freely by means of handles. The ends of the coil A were connected with the coil in the galvanometer frame. A quick motion of the coil generated an induced current, which reached the galvanometer frame through the wires, and caused the magnetic rod to be deflected. The direction of deviation was determined by the direction in which the coil was moved, and it is evident that by combinations of these deflections a whole alphabet could be formed. To simplify the manipulations, a double lever L was added, which moved a commutator as well as the coil. The call signal was given by means of a bell and clockwork.

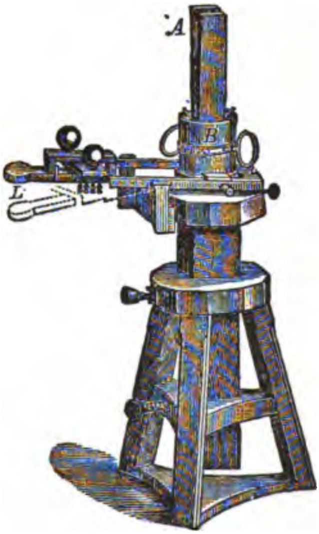


Fig. 310.—Gauss and Weber's Sending Apparatus.

Although Messrs. Gauss and Weber's communication of signals at Göttingen in 1833 was the first accomplishment of telegraphic communication by means of electricity, and realized the fancy of Strada, quoted by Addison, of sympathetic magnets, yet their invention was regarded merely as an appendage to a magnetic observatory, and several years elapsed before we hear more of the new invention. The year 1837 is the date of the realized electric telegraph. We find three distinct claimants, of whose independent merits there is no reason whatever to doubt, though how much of the merit of all must be considered due to Messrs. Gauss and Weber, who first made the experiment described above, though they did not offer it for general adoption in a convenient form, is a matter which we need not here attempt to decide. The three independent inventors are Carl August von Steinheil, of Munich, who had been a pupil of Messrs. Gauss and Weber; Mr. Wheatstone, of London; and Mr. Morse, of the United States. The telegraph of the two last resembles in principle Oersted's and Gauss's; that of the first is entirely original, and consists in making a ribbon of paper move by clockwork, whilst interrupted marks are impressed upon it by a pen or stamp of some kind brought in contact with the ribbon by the attraction of a temporary magnet, which is excited by the circulation of the telegraphic current of electricity. In the telegraph of Mr. Wheatstone, the needle moves only to the right or left, and by the combination of a certain number of right and left motions, either with one or two independent needles acted on at once by distinct currents, the alphabet is easily, though somewhat tediously, constructed.

It thus appears that we cannot claim the exclusive invention of electric telegraphy for any one individual. But of the several inventors none probably has shown such perseverance and skill in overcoming difficulties as Mr. Wheatstone. His telegraph, accordingly, was in general use in England before Von Steinheil was able to obtain a similar success in Germany. The telegraphs of Mr. Morse have this inestimable advantage, that they preserve a permanent record of the despatches which they convey. We will now examine the points of difference of the earliest instruments of these several inventors more in detail.

Carl August von Steinheil was born in 1801; he studied science first at Göttingen under Gauss, and then at Kõnigsberg. He was appointed in 1835 Professor of Physics and Mathematics at Munich. In 1849 he was invited to Vienna by the Austrian Government to superintend the establishment of telegraphic communications, and there he prepared a complete telegraph system for the different provinces of the empire. When he returned to Munich, in response to the wishes of the King Maximilian II., he founded in 1854 the optical and astronomical laboratories which have since become so famous, and became a member of many different scientific societies. He died in 1870.

Steinheil undertook the further perfection of the Gauss-Weber telegraph, and in his hands the apparatus became the first writing telegraph, which is shown in fig. 311 (*La Lumière Électrique*). The sending apparatus consists of a kind of Pixii's machine (which may be seen on the right in the figure, where a portion of the case is removed for the purpose). In this generator the induction coils can be moved past the magnet-poles by means of a horizontal lever weighted with balls. The induced currents thus obtained receive the one or the other direction, according to the direction in which the coils are moved. The receiving apparatus consists of a galvanometer frame A, in which there are two magnetic needles, which turn about the vertical axis *a d'*. Each has a color-pot, or small ink-holder, and a small brass adjustment, and is held in a certain position by a controlling magnet. When a current flows in one direction through the coil, the brass adjustment of one of the needles strikes against a bell; if the current flows in the other direction, the brass piece of the

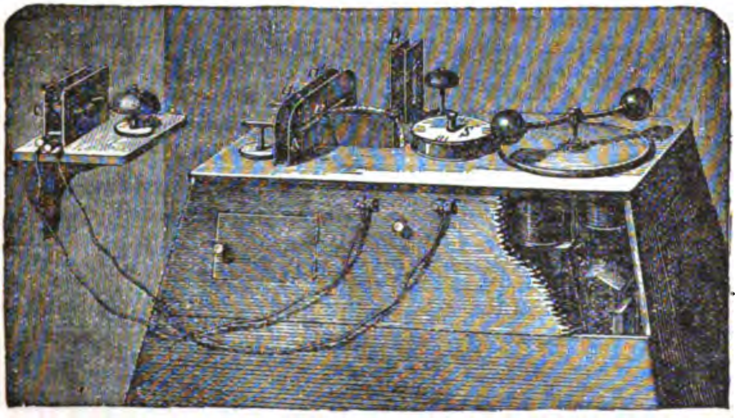


Fig. 311.—Steinheil's Telegraph.

second needle strikes against the second bell. In the same manner a current of one direction passes the ink-holder of one needle, and a current of the other direction the ink-holder of the second needle, against a paper strip *r*, which by means of some wheel-work is moved with uniform velocity past the two holders. The bells are not drawn in the figure. When the bells are used the alphabet is formed by a combination of strokes; when the ink-holders are used, by combinations of points; as, for instance, *s* = . . · ·, *t* = : , *e* = . , *n* = . . , and so on. The two alarms B and C, also shown in the figure, consist simply of a coil in which a magnet swings about a vertical or horizontal axis, and strikes against a bell. Steinheil used this instrument for corresponding between the Observatory at Bogenhausen and his private residence at Munich, the total length of the wire being 37,500 feet.

Steinheil it was who further discovered the possibility of conveying the returning electric current back through the earth, a discovery which was of the greatest utility in the further development of telegraphy; indeed, no discovery is perhaps more deserving of notice, on account of its importance, than this of the apparently infinite conducting power of the earth, when made to act as the vehicle of the return current. Setting all theory aside, it is an unquestionable fact that if a telegraphic communication be made, suppose from London to Brighton, by means of a wire going thither, passing through a galvanometer, and then returning, the strength of the current shown by the galvanometer at Brighton will be almost exactly doubled if, instead of the return wire, we establish a good communication between the ends of the conducting wire and the mass of the earth at Brighton and London. The whole resistance of the return wire is at once dispensed with. The fact was more than suspected by Steinheil in 1838; but, from some cause or other, it obtained little publicity; nor does the author appear to have exerted himself to remove the reasonable prejudices with which so singular a paradox was naturally received. A most ingenious inventor, Mr. Bain, whose chemical telegraph we shall describe, independently discovered the principle, and proclaimed its application somewhat later;

and in 1843 perhaps the first entirely convincing experiments were made by M. Matteucci, at Pisa. From this time the double wire required to move the needle telegraph was reduced to a single one. The explanation of this curious fact appears to be, not that the electricity is conducted back by the earth to its origin at the battery, but that the molecular disturbance communicated along the conducting wire, in consequence of the difference of potential produced by the battery being effectually relieved by perfect communication with a vast reservoir of zero potential and infinite capacity like the earth, proceeds in an uninterrupted manner, and to an unlimited extent.

Meanwhile the needle telegraph had undergone some further modifications. William Fothergill Cooke, who had seen Schilling's apparatus in 1836 at Professor Munke's house in Heidelberg, copied it, and brought it to England. Intent on improving the apparatus, he joined Wheatstone, and together they constructed a needle apparatus with four, and another with five, needles. The latter is represented in fig. 312. The signs were given by the deviation of two needles at the same time. As may be seen from the drawing, twenty different signs could be given by the apparatus. Cooke and Wheatstone took out their first patent in 1837. It is important to note that a local circuit was used for working the alarm, as this represents the first application of a transmission apparatus, the so-called relay. By inventing the relay, the principle of which is that a current too weak to do the work itself may cause a strong local current to do the work for it, Wheatstone made it possible to telegraph on long lines with comparatively weak currents, only just strong enough to close the local battery by means of the relay, which does the real work, and sets the receiving apparatus in motion. The relay was first used with the alarm only, in the form shown in fig. 313. The current coming through *l l'* passes the coil M, disturbing the equilibrium of the magnetic needle, movable about the axis *x y*, and causing the lever *a b* to lower its end *a*, and to dip into the mercury cup. The local battery B, which has to excite the electro-magnet E, has now a closed circuit. The magnet E, which is in this circuit, attracts its armature, and the pin S is made to strike against the bell G. This transmission apparatus causes a powerful effect of the magnet E, even when only a weak current arrives at the station.

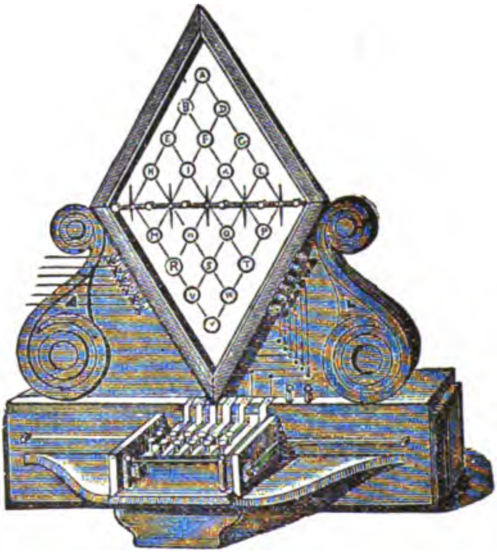


Fig. 312.—Cooke and Wheatstone's Five-Needle Telegraph.

The first experiment with this five-needle apparatus was made at the Northwestern station with a wire of 1¼ miles. In 1840 the Great Western Company constructed a line 39 miles long, but did not extend the line any farther on account of the expense.

The first pointer telegraph which worked well was that invented by Wheatstone, in 1839, which is represented in fig. 314. The sign-giver here consists of a ratchet wheel K. The springs *n n'* are so arranged that when one spring makes contact with a tooth, the other spring will stand between two teeth. The negative pole of the battery is connected with the metal mass of the wheel, and the current flows from the positive pole to the receiving station. The receiving apparatus consists of the electro-magnets *e e'*, with the two armatures *a a'* and the clock work *u*, whose pointer *z* moves over the different signs, the clockwork being put in motion by the weight G. The wire + *l* of the sending station leads to the clamp K of the receiving station; clamps K_1 and K_2 of the receiving station are connected with the springs *n n'*; when the wheel K is moved the battery current will alternately flow through the electro-magnets *e* and e_1, passing through the electro-magnet *e* when the spring *n* rests upon a tooth, as shown in the figure, and through the electro-magnet e_1 when the spring *n'* comes to rest upon a tooth. Owing to the alternate excitement of the two electro-magnets, an alternate attraction of the armatures *a a'* will take place, and, therefore, a swinging backward and forward of the escapement.

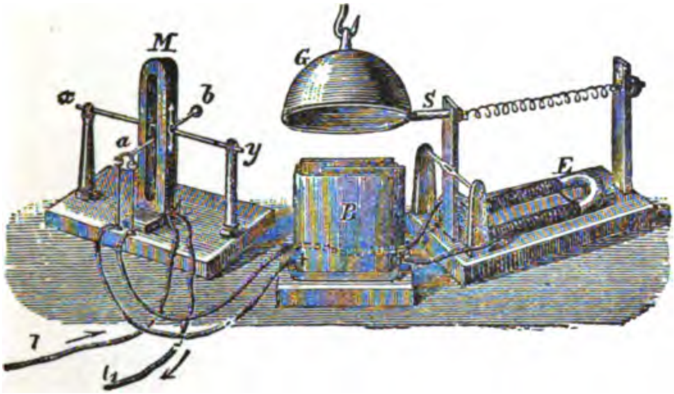


Fig. 313.—Wheatstone's Relay.

Of all the many forms of telegraph apparatus none has been more extensively employed than the one devised by Morse; but although he has done much for telegraphy, the actual invention of the apparatus that bears his name was probably suggested to him by experiments made by others; this may be proved by the following sketch of Morse's labors and life, taken from J. Hamel's ***Entstehung der Galvanischen und Elektromagnetischen***

Telegraphie:—Samuel Finley Breese Morse was born in 1791, at Charleston, Mass., where, until he reached the age of forty, he devoted his time to painting. He visited Europe twice, in 1811—1815, and in 1829—1832. On his return voyage to America he made the acquaintance of Professor Charles V. Jackson, of Boston, and on board ship Morse saw Jackson's experiments in electricity,

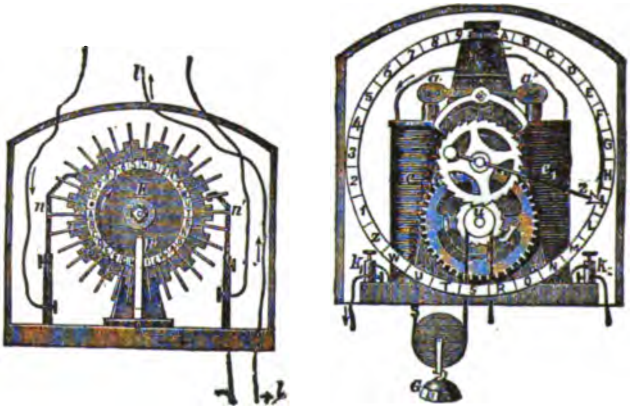


Fig. 314.—Wheatstone's Pointer.

which suggested to him the possibility of using electricity for signalling. When he returned to America, Morse again for a time devoted himself to painting. In November, 1835, he resumed his telegraphic experiments, but obtained no results of any value because of his lack of knowledge on the subject. In 1836 he received several hints from a professor of chemistry, Leonard Gale, who afterwards became Morse's partner.

In 1837 an apparatus was constructed which made the electric transmission of signs by combinations of two simple motions possible, nine signs being used to represent the figures 1—9. Fig. 315 represents Morse's apparatus for the transmission of these nine numbers. The frame *c c* is vertically fastened upon a table, and carries a kind of pendulum *o* B and the electro-magnet E. Upon the pendulum is fastened the armature of the electro-magnet, which bears a pencil at the lower end; a paper strip passes over the roller R underneath the pencil, and is kept in

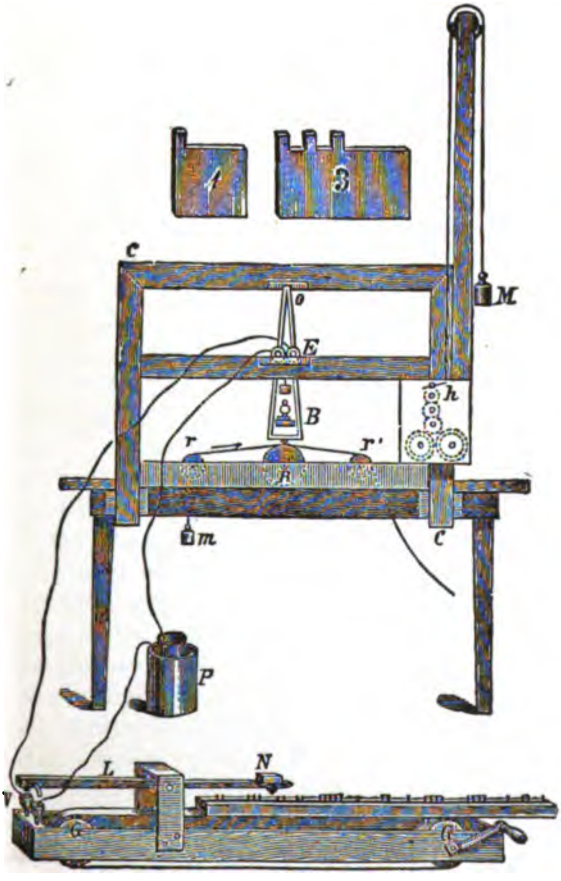


Fig. 315.—Morse's First Telegraph.

motion by means of the clockwork *h* and the rollers *r r'*. When the pendulum is in its normal position the pencil traces lines upon the paper that are parallel in direction to the length of the strip; when the armature is attracted a slanting line is traced by the pencil, and another slanting line is traced when the magnet lets the armature go, and the pendulum returns to its original position. By alternate magnetization and demagnetization V-shaped lines are formed. One V indicates the figure 1; two Vs the figure 2; and so on. These deflections of the pencil are produced in the following manner: The lever L of the sign-giver has the weight N placed at one end, and under this a pin; at the other end a bent wire is arranged, which, when dipping into the mercury cups V, connects them with each other, and by doing so closes the circuit of the battery P and electro-magnet E. The types are placed in the wooden frame A. When A is made to move under the lever N, the lever will close the circuit as often as the edges of the lead types raise the lever-end N. The pencil at B will, therefore, make corresponding signs on the paper strip. About the time when this apparatus was constructed, Morse made the acquaintance of Alfred Vail, who aided him greatly, and afterwards became one of Morse's partners. The experiment succeeded for the first time on the 4th of September, 1837. The signs obtained were those shown in fig. 316, which correspond to the numbers 215, 36, 2, 58, 112, 04, and 01837, which, according to the telegraphic dictionary, gave the words, "Successful attempt with telegraph, September 4, 1837." Morse's apparatus became known to Francis O. T. Smith, a member of Congress, and through his aid Morse was enabled to make a journey to London and Paris, which, however, proved fruitless as regards the finding of means to give effect to his invention. When he returned to New York (1839) Morse again took to painting, and afterwards to Daguerreotyping, in order to maintain himself. In 1843 Congress voted the sum of $30,000 for the construction of a trial line, and, as a consequence of this grant, the first line in America of 40 miles was tried for the first time in 1844, between Washington and Baltimore.

Morse's apparatus had, meanwhile, undergone many modifications, so that by this date it closely resembled the form now usually employed. From that period the Morse apparatus had a large demand, and in a very short time became widely if not generally used. Morse became electrician of the New York and Newfoundland Telegraph Company, and also of the New York, Newfoundland and London Telegraph Company, and about the same time he was further appointed Professor of Natural History at Yale College, New Haven. In 1857 he received a present from ten European States of 400,000 francs, as an acknowledgment of his international services. Two monuments were erected to him in New York—one in 1871, the other in 1872, the year of his death.

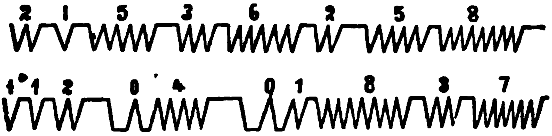


Fig. 316.—Morse's Writing.

The Morse instrument, which has been greatly improved in Europe, is equalled if not surpassed in usefulness by Hughes' printing instrument. This and the Morse apparatus have been declared by the International Telegraph Congress to be the only exclusively reliable instruments for the international telegraph service. The first printing telegraph instrument, however, was constructed by the American, Vail, in 1837. Bain followed in 1840, and Wheatstone in 1841. David Edwin Hughes was born in London, in 1831, but emigrated with his father to Virginia in 1838, where he was appointed Professor of Music at the High School, Barnstown. Here he studied natural science with such success that after some time the professorship was offered to him. He devoted his time for some years to the construction of a type-printing telegraph apparatus, which he completed in 1853. A society in New York was formed, which undertook the introduction of the printing apparatus in America, whilst Hughes himself went to Europe for the purpose of making his instrument known. He met with no success in England, but was able to introduce the instrument into France, whence it very soon reached other countries. The chemical telegraph, which had been first constructed by Sömmerring, was so much improved in the course of a few years that it was of practical use to Bain in 1842. The principle consists in causing the end of the wire of the receiving station to move over a paper soaked in a solution that will be decomposed when a current flows through the wire, and regulating the flow of current from the sending station, so that the decomposition and consequent coloring of the paper appear as written or printed letters. The word to be telegraphed is compounded of large simple metal letters, as shown in fig. 317. These are connected with the positive pole of a battery, the negative pole of which reaches the earth. A metal plate, which is connected to earth, and upon which the paper containing the salt solution to be decomposed is laid, is arranged at the receiving station. The brush *b* at the sending station, which consists of five metal springs, is connected by means of the cable K K′ with a similar brush *b′* at the receiving station, so that the first spring of *b* is connected with the first spring *b′*, and so on. If the brush *b* is moved over the metal letters, and the brush *b′* is moved at the same time and with the same velocity over the prepared paper on the metal plate, a circuit is closed as often as a spring of the brush *b* comes in contact with the metal letters, and consequently a current flows through the springs of the two brushes, which decomposes the salt solution and leaves a visible mark. For this purpose potassium iodide in starch may be taken. The iodine is separated out by the current, and turns the starch blue or violet, in which color the letters appear. The chemical tel-

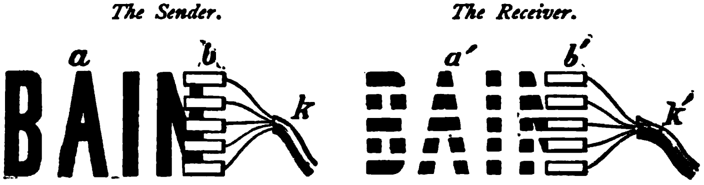


Fig. 317.—Bain's Chemical Telegraph.

egraph has been modified by Stöhrer, Siemens, Gintl, and others. The copying telegraph by Bakewell and Bonelli, as well as the pantelegraph by Caselli (1856), may be classed among these.

After it had been found out that instead of using several wires one sufficed, it was thought possible still further to utilize this one wire; this led to the discovery of duplex telegraphy and multiplex telegraphy. We owe the invention of the duplex system and the first practical experiments concerning it to Professor F. A. Petrina and to the late director of the Austrian Telegraph Service, William Gintl (born 1804, died 1883). An apparatus constructed by Gintl was used in these experiments, because the Morse apparatus offered difficulties. In 1854, Frischen, in Hanover, and Siemens, independently of each other, invented duplex methods. Maron gave a method based on the principle of Wheatstone's bridge in 1863. A number of other proposals were made, to which no attention was paid until the American Stearns published his duplex apparatus. By a duplex method of sending on telegraphic lines is meant the transmission of telegraphic signs in opposite directions simultaneously along one and the same wire. Multiplex telegraphy has for its object the better utilization of one wire, so that several operators may send currents through one and the same wire. If, for instance, with a single system, eight signs can be given in one second, by eight currents passing during that time through the leads; with a multiplex arrangement, in one second one hundred and more currents may be sent through the leads, which proves that the wire is only partly utilized when worked with the single system. Newton gave a method for the better utilization of the wires as early as 1851, and Rouvier, Hughes, and others followed Newton's plan more or less closely. Duplex systems for Morse writing have been recently devised by B. Meyer and A. E. Granfield; multiplex systems for the Hughes apparatus, by Baudot and Schäffler.

Cable Telegraphy.—Before we close our short sketch of the historical development of telegraphy, we may make a few remarks regarding the development of cable telegraphy. As early as 1774, when it was proposed to employ frictional electricity for telegraphical purposes, Le Sage, in Geneva, suggested the construction of a conducting cable; for this purpose glazed earthenware tubes were to be furnished with partitions of the same material, having holes through which the wires were to be taken. The telegraph apparatus consisted of double pith ball pendulums for each letter. In 1809 Sömmerring covered the wire with a solution of caoutchouc, in order to convey it unhurt through water. In 1812 Schilling succeeded in exploding powder-mines by means of insulated wires which led across the Neva. Shortly before his death he made preparations to connect Cronstadt with Peterhof by means of a cable, which was intended to be sunk in the Gulf of Finland. Jacobi, in Petersburg, in 1842, used a specially prepared wire, which was enclosed in glass tubing, and then embedded in fine sand. With the introduction of gutta-percha, in 1843, a new era commenced for the construction of cables. Siemens used gutta-percha insulation for the first trial line. The new insulating material seemed to do good service, and Prussia, Austria and Russia at once used it for their underground leads; the insulation of the leads, however, went from bad to worse, so that the Prussian Telegraph Direction in 1852 was forced to discontinue using it. In 1840 Wheatstone proposed to connect France with England by means of a cable. In 1842 Morse made successful experiments in the harbor of New York, and also warmly advocated the cable connection of America with Europe. In 1845 Ezra Cornell succeeded in connecting Fort Lee with New York (a distance of twelve English miles) by means of a cable which was laid in the Hudson. This cable did good service till 1846, when it was destroyed by the ice. In 1850 Dover and Cape Grisnez were connected by means of a cable, which lost its insulation the day after it had been laid by its friction against the rocks. The cable laid in 1857 by the Submarine Telegraph Company, between Dover and Calais, was protected by a cover of iron wire, and remained in use until 1875. The first attempts to connect England with Ireland were made in 1852. After failing twice, a cable was laid between Cagliari and Bona in 1860.

The Atlantic Cable.—Cyrus Field had meanwhile established a company in America (in 1854), which had obtained the right of landing cables in Newfoundland for fifty years. Soundings were made in 1856 between Ireland and Newfoundland, showing a maximum depth of 4,400 metres. Having succeeded, after several attempts, in laying a cable between Nova Scotia and Newfoundland, Field founded the Atlantic Telegraph Company in England, which decided to make use of a cable such as that shown in fig. 318. Each of the six copper wires in the centre had a diameter of 0.76 millimetres, and was covered by three layers of gutta-percha; these were enclosed in a covering of tarred jute, and the whole was covered by eighteen cables, each consisting of seven iron wires. The length of the whole cable was 4,000 kilometres, and was carried by the two ships *Agamemnon* and *Niagara*. The distance between the two stations on the coasts was 2,640 kilometres. The laying of the cable commenced on the 7th of August, 1857, at Valentia, (Ireland); on the third day the cable broke at a depth of 3,660 metres, and the expedition had to return. A second expedition was sent in 1858; the two ships met each other half-way, the ends of the cable were joined, and the lowering of it commenced in both directions; 149 kilometres were thus lowered, when a fault in the cable was discovered. It had, therefore, to be brought on board again, and was broken during the process. After it had been repaired, and when 476 kilometres had been already laid, another fault was discovered, which caused another breakage; this time it was impossible to repair it, and the expedition was again unsuccessful, and had to return. In spite of the repeated failures, two ships were again sent out in the same year, and this time one end

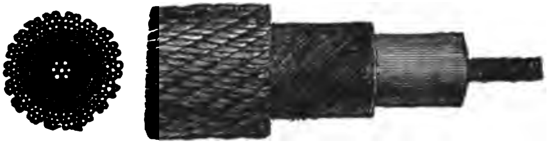


Fig. 318.—The First Atlantic Cable.

of the cable was landed in Ireland, and the other at Newfoundland. The length of the sunk cable was 3,745 kilometres. Field's first telegram was sent on the 7th of August, from America to Ireland. The insulation of the cable, however, became more defective every day, and failed altogether on the 1st of September. From the experience obtained, it was concluded that it was possible to lay a trans-Atlantic cable, and the company, after consulting a number of professional men, again set to work. Of the samples sent in by the different makers, that of the firm of Glass, Elliott and Company was considered likely to answer the purpose best, and an order was given for 4,266 kilometres. Fig. 319 shows the different parts of the cable, viz.: a copper strand of seven wires, a gutta-percha envelope consisting of four layers, a cover of tarred hemp, and an outer coating of iron wires covered with hemp. The *Great Eastern* was employed in laying this cable. This ship, which was 211 metres long, 25 metres broad, and 16 metres in height, carried a crew of 500 men, of which 120 were electricians and engineers, 179 mechanics and stokers, and 115 sailors. The management of all affairs relating to the laying of the cable was entrusted to Canning. The coast cable was laid on the 21st of July, and the end of it was connected with the Atlantic cable on the 23d. After 1,326 kilometres of cable had been laid, a fault was discovered, an iron wire being found stuck right across the cable, and Canning considered the mischief to have been done with a malevolent

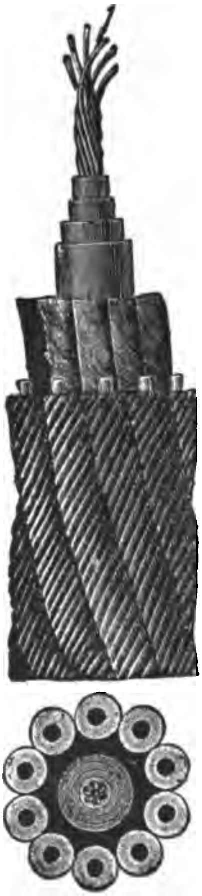


Fig. 319.—The Second Atlantic Cable.

purpose. On the 2d of August, 2,196 kilometres of cable were sunk, when another fault was discovered. While the cable was being repaired it broke, and attempts to recover it at the time were all unsuccessful; in consequence of this the *Great Eastern* had to return without having completed the task.

A new company, the Anglo-American Telegraph Company, was formed in 1866, and at once entrusted Messrs. Glass, Elliott and Company with the construction of a new cable of 3,000 kilometres. Different arrangements were made for the outer envelope of the cable, and the *Great Eastern* was once more equipped to give effect to the experiments which had just been made. The new expedition was not only to lay a new cable, but also to take up the end of the old one, and join it to a new piece, and thus obtain a second telegraph line. The sinking again commenced in Ireland on the 13th of July, 1866, and it was finished on the 27th. On the 4th of August, 1866, the Trans-Atlantic Telegraph Line was declared open.

Since then other Atlantic cables have been laid, and the great ocean is now spanned by no fewer than nine such links of communication, the last of which was successfully deposited in 1886. A steamer specially constructed is now employed, as far less expensive than the *Great Eastern*, and the laying of the last cable occupied no more than twelve days, without the slightest hitch or interruption from beginning to end. The later cables do not differ in general construction from those described above; but improvements in details have produced greater strength, and better insulation and conductivity. There is now no practical limit to the length of cable which could be laid if required. beyond the contingencies of severe weather.

MODERN TELEGRAPHY.

The above historical outline will enable us to classify the various systems that are at present in use for the transmission of telegraphic signals. These signals are of two kinds, *visible* and *audible*. Visible signals are either *permanent* or *transient*, according as they are produced by *recording* or *non-recording* instruments. Thus we have—

Non-recording Instruments—I. Needle Instruments.
II. Sounding Instruments.
(1) The Sounder.
(2) The Bell.
III. Dial Instruments.
Recording Instruments — IV. Bain's Chemical Marking Instrument.
V. Morse's Instruments.
(1) The Embosser.
(2) The Ink-writer.
VI. Type-printers.

I. NEEDLE INSTRUMENTS.

The needle is a pointer capable of receiving two distinct motions, the one to the right and back, and the other to the left and back; its position, when it is at rest, being vertical. In the earliest needle system there were, as we have seen, as many as twenty-six needles. In Cooke and Wheatstone's instruments there were five needles. The number was reduced to two, and finally, in the latest use of the system, to one. Combinations of the two swings of the needle spell out the alphabet just as, when recording instruments are used, the combinations of long and short strokes form all the necessary signals. A single motion to the left forms the letter *e*, and one to the right the letter *t*. By writing *l* for a nod of the needle to the left, and *r* for a nod to the right, the alphabet will appear as follows:

A	lr	H	llll	O	rrr	V	lllr
B	rlll	I	ll	P	lrrl	W	lrr
C	rlrl	J	lrrr	Q	rrlr	X	rllr
D	rll	K	rlr	R	lrl	Y	rlrr
E	l	L	lrll	S	lll	Z	rrll
F	llrl	M	rr	T	r		
G	rrl	N	rl	U	llr		

Needle instruments are of two kinds, named from the keys or commutators attached to them, the ***drop-handle*** and the ***tapper.*** The drop-handle is simply a commutator worked by a handle (fig. 320), so that a motion of the handle to the left connects the the copper pole of the battery with the line-wire and puts the zinc pole to earth, and a motion to the right connects the zinc pole with the line-wire and puts the copper pole to earth. The receiving instrument is so connected that the former motion of the handle produces a nod of the needle to the left, and the latter a nod to the right.

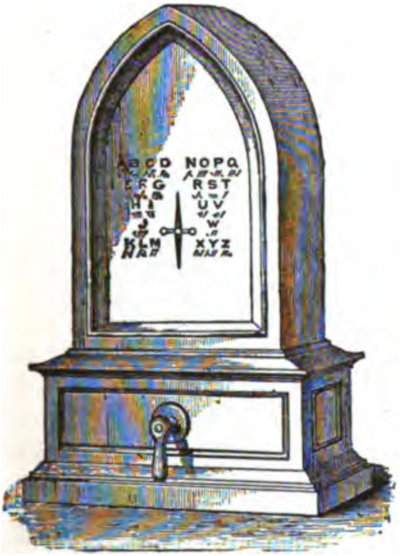


Fig. 320.—Single Needle Instrument.

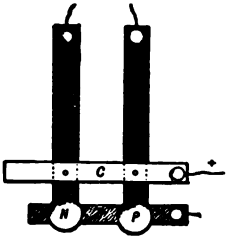


Fig. 321.—The Tapper.

The tapper consists of two bars of brass or copper Z and C (fig. 321) connected with the battery, and two metal springs L and E, one of which, L, is connected with the line, and the other, E, is put to "earth." The springs both pass under C and over Z, and when not pressed on they both touch the bar C, but do not touch the bar Z. One spring must be pressed down to make the circuit. When the finger is pressed upon the knob N of the spring L, it connects L and Z and sends the current from zinc to the line, and from E back to C. If the knob P on E is pressed down, the current goes from zinc to "earth," and from the line back to C. To depress N causes the needle of the receiving instrument to nod to the left, to depress P causes the needle to nod to the right.

II. SOUNDING INSTRUMENTS.

The signals given by the sounding instruments are, like those of the needle, transient, and the instruments are non-recording. They appeal, however, to the ear instead of to the eye. There are two kinds of sounding instruments, the *sounder* and the *bell*. The clerk in charge of a needle instrument has often been known to recognize by the ear when the needle strikes the pin or stop on the left, and when it strikes the stop on the right, and so to be able to write down the message without looking at the instrument. In this case even the needle instrument may be said to act as a sounder. The simple *sounder*, however, is but an electro-magnet with an armature in the form of a lever, like the instrument represented in fig. 322. The end of this lever moves between two stops, one of which it strikes when attracted, and the other when released. The time elapsing between the two sounds is short or long, the short corresponding to a nod to the left in the needle, or to a dot in Morse's system, and a long interval to the nod to the right, or to the dash. The sounder has been introduced into America, and has there supplanted all other forms of apparatus. It is also almost universally employed in India.

The earliest form of acoustic instrument used in England was probably Bright's bell. In this instrument two bells of different tone are used, the hammer of one being actuated by currents in one direction, and that of the other by currents in the other direction. The sound of one bell corresponds to dots, and that of the other bell to dashes. The sending apparatus is the same as the tapper of the single needle, and relays and local currents are often needed. The instrument is probably the quickest non-recording instrument extant, but it is complicated in its construction and difficult in its adjustment compared with the sounders. Other bells will be described under the head of special signalling apparatus.

The key required for the sounder is the single Morse key, represented in fig. 322. Three brass bars N, M and V are fastened upon a basement block of wood A; M has the two brass cheeks D D arranged upon it, as chairs or bearings for the support of the axis B. The lever *b b′* moves about this axis, moving in the one direction by the hand of the operator pressing on the knob G, and returning when released in consequence of the tension of a spring *f;* and steel or platinum contacts *c a* are screwed into the bars N and V, the corresponding contact-pins of which pass through the lever *b b′*. One end of the spiral spring is attached to the lever at *b*, and the second end is fastened to the bar M. This spring serves to hold the lever down upon the contact *c*, which is regulated by the screws S *s*. The line-wire is connected with the middle plate M, the receiving apparatus with N, and the sending apparatus, including the home battery, with V. Hence the key is always set ready to receive a message, but must be pressed down to send one.

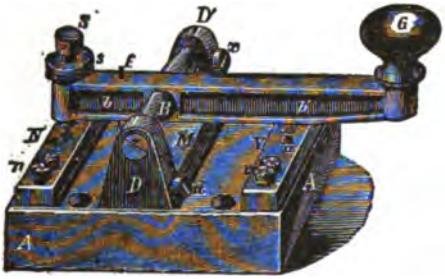


Fig. 322.—The Morse Key.

III. DIAL INSTRUMENTS.

Wheatstone's A B C System.—The indicating instrument in this system has the letters of the alphabet arranged on a dial, and a pointer is placed in succession opposite the letters that spell out the message. The currents are produced on the principle of a magneto-electric machine turned by means of a handle, which also causes the rotation of the pointer over the face of the dial. There is a key opposite each mark on the dial, and an endless chain passes inside all the keys, passing over a number of small pulleys. When the handle is turned the pointer receives four impulses for each revolution, and moves over four spaces. If, however, a key is depressed, the pointer is arrested when it comes opposite to it, and at the same time the current, instead of going to the line, is cut off. When the key is raised again, supposing the handle to be continuously turned, the pointer resumes its course until another key is depressed. Now the dial of the receiver is exactly like that of the sender, and the motion of its pointer is regulated by an escapement wheel propelled by an electro-magnet. The escapement wheel has fifteen teeth, and a complete revolution of the handle of the sender causes it to move two teeth forward, so that the pointer moves over four

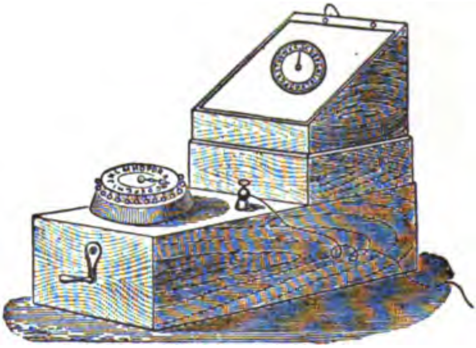


Fig. 323.—Wheatstone's A B C Apparatus.

letters like the pointer of the sender. Hence, the pointers of two stations properly connected and having instruments properly adjusted move synchronously. To secure that both pointers start from the zero point of their dials, the keys of these points are kept depressed. The system works well for private stations.

Bréguet's Dial Telegraph.—In the apparatus just described no battery is employed, but the current is furnished by magneto-electric induction in the act of manipulation. Of A B C systems, where a battery is employed to furnish the current, Bréguet's Dial Telegraph is a good example, and is illustrated in figs. 324—327. The transmitting and receiving instruments are distinct and different. The transmitting apparatus is shown in fig. 324. It has a dial, round the face of which are placed the letters of the alphabet, and the sign +, which is used to divide words; and in another row are placed numerals, as far as 25. A small notch will be seen cut in the rim opposite each letter. A handle M is pivoted to the centre, the arm having a slot cut in it, and this is turned round (in one uniform direction only, never backward) till the letter or figure required appears through

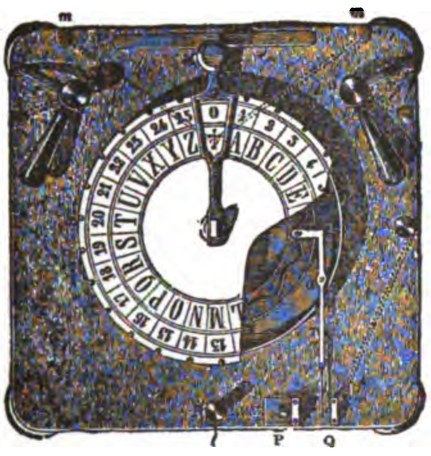


Fig. 324.—Bréguet's Transmitter.

the slot, a small pin on the under side catching in the notch, and keeping the position exact. If the letter is overshot the arm must not be moved back, but carried round again; hence the need of the slot and pin, not otherwise material. The removed part of the dial shows a wheel beneath which turns with the handle, and has cut in it a waved groove, having half the number of waves that there are letters, so providing either a crest or a hollow for each. A roller on the end of the bent lever T works in this groove, so that in turning the handle one revolution the lower end of T is moved from side to side twenty-six times, or thirteen to-and-fro complete motions. At the bottom of the lever a platinum spring thus comes alternately into contact with the contact-screws P and Q. P goes to the line-wire, while the battery-wire goes to *m*, passing thence to the grooved wheel, and so to the lever T.

The receiving apparatus is shown in figs. 325—327. Fig. 325 is the face, showing a small key-axis between the numbers 25 and 1 on the dial, by which the clockwork in the interior is wound up. Fig. 326 is a back view, showing interior parts, except that the magnet, which faces the dotted circles of the armature A, is removed for clearness. The clockwork causes the pointer to travel round the face rather quickly until stopped or regulated by the escape-wheel D, a larger view of which is given in fig. 327. It comprises two ordinary notched wheels mounted on one axis, so that the teeth alternate. The pallet *i* underneath, as it vibrates backwards and forwards, alternately catches the tooth of each wheel in succession, so that if there are thirteen teeth on each, every movement of the pallet enables the wheel to revolve one twenty-sixth of a revolution. The pointer is fixed to the axis of this wheel, so that in the same period it also moves forward the space of one letter. The armature A (fig. 326) swings to and from the observer from suspending pivots fixed in the projecting supports V V′, and carries with it the arm *l*, having a horizontal pin C projecting from one end of it. A spiral spring *f* draws the armature back when the current does not pass through the coils of a horseshoe electro-magnet, whose poles are opposite A. The armature, and with it the pin C, therefore swing backwards and forwards as current is made and broken: and in the enlarged view of the escape-wheel in fig. 327 it will be seen how this motion of the pin *c* in the fork *d* works the escapement, thus causing the pointer to move round the dial one step for every "make" or "break" of current.

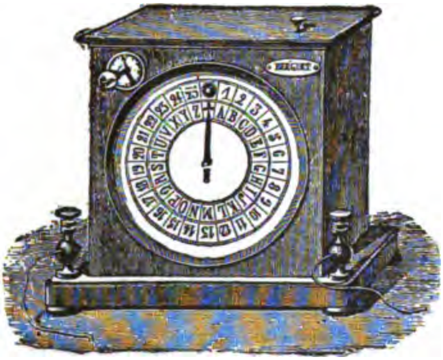


Fig. 325.—Receiving Instrument.

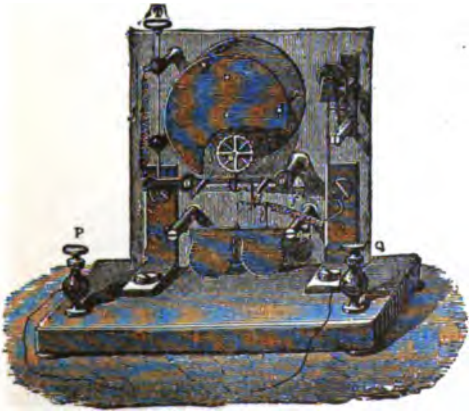


Fig. 326.—Construction of Receiver.

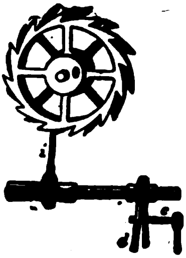


Fig. 327.—Escape-Wheel.

The action of the two instruments can now be readily understood. It has been seen that a complete revolution of the pointer of the sending instrument makes and breaks current thirteen times, or makes twenty-six changes; and these twenty-six changes also move round the pointer of the receiving instrument a complete revolution. Any lesser number of steps is similarly reproduced in the receiving instrument.

This instrument works in practice remarkably well. Occasionally the pointer will get wrong, owing to mistake or interruption in the message; in that case the head of the rod T is depressed, which liberates the escapement altogether until it has rotated back to the sign +, when all starts correctly again. The handles near the top of the instruments direct the current to a signal-bell on the receiver at pleasure.

IV. CHEMICAL MARKING INSTRUMENTS.

Bain's invention for signalling by means of the electrolytic effects of a current has already been described. It was at one time the only recording instrument used in England, but it has been gradually supplanted by the Morse. As, however, it registers its messages with great rapidity, the demand for speed may lead to its restoration to favor. We have but two additions to make to the description already given: first, to point out the importance of attending to the order of the connections, and secondly, to give the composition of suitable solutions. If the sending key be of the kind shown in fig. 322, the wire from the copper pole of the battery must be brought to the front bar V. If the current be sent in the opposite direction, no mark will be made by the printer. The *starch solution*, already mentioned, consists of one part of potassic iodide with twenty parts of starch, diluted by forty parts of water. The *prussiate of potash solution*, which is commonly used, consists of one part (by measure) of prussiate of potash (potassic ferrocyanide), one part of ammoniac nitrate (a saturated solution), and two parts of water. The effect of the ammoniac nitrate is to keep the paper from drying.

V. THE MORSE SYSTEM.

(1) *Embossers.*—The Morse apparatus consists of an electro-magnet and a printing arrangement, which is furnished with wheelwork, and a disc with telegraph paper. The electro-

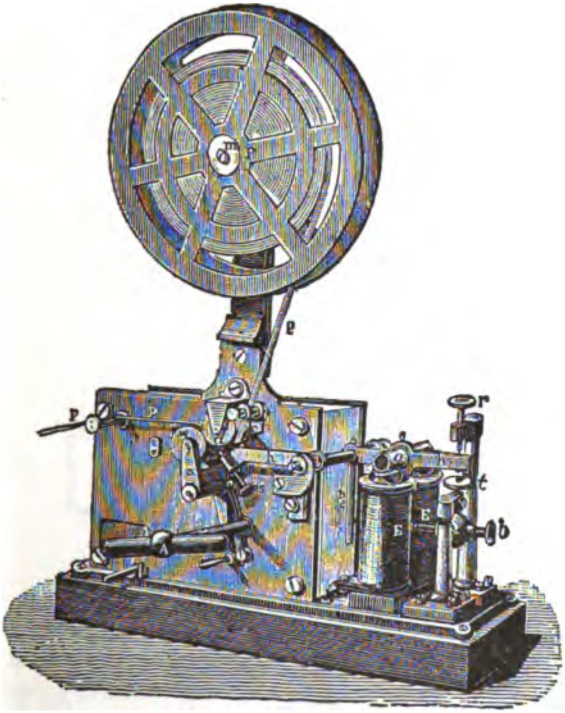


Fig. 328.—The Morse Embossing Instrument.

magnet E E (fig. 328) consists of two cylindrical cores of very soft wrought iron, which are connected at their lower ends by an iron plate, so that they form a horse-shoe magnet. Both arms have a great number of turns of insulated copper wire round them, and are connected in such a manner with the scource of electricity, and with each other, that the magnet has a north pole and a south pole at its upper ends. The armature *a* of the electro-magnet, and the pencil s, are fastened to the lever *h*, which can move about a horizontal axis. The lever is connected with a spiral spring, attached to a screw *b*, which when turned in the right direction increases or diminishes the tension of the spring, and therefore offers a greater or lesser resistance to the attraction of the armature by the magnet. The play of the lever is limited by the contact-screws *r* and *t*. The printing arrangement by which the signals are impressed on the strip of paper drawn off the wheel may be understood from fig. 329. In both figures the various parts are indicated by the same letters. The end of the lever *h* is split, and the pencil s is placed in this slit. This pencil is adjusted by means of the knob s_1, and ends in a blunt but glass-hard point, which serves the purpose of marking the paper. When the pencil is arranged in the right position, it is maintained in it by tightening the screw *n*; *d* is the printing roller, which turns round the axis a_2, and has a groove at B in order to facilitate the marking of the pencil. The paper is held between the rollers *d* and *w*, and the pressure of *d* upon *w* is regulated by means of the spring *q q*, one end of which

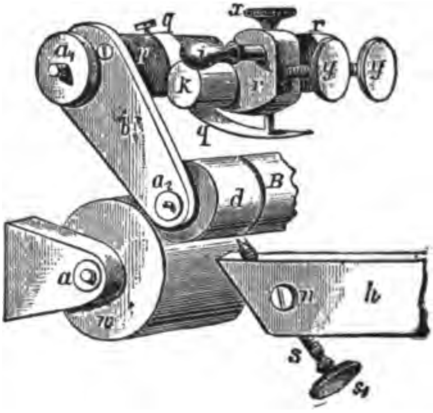


Fig. 329.—The Morse Writer.

is fastened to the axis *p* of the brass piece *b*, so that the spring presses against the metal piece K; the second end of the spring presses against the screw *x*, and thus the pressure can be regulated by turning the screw; *r r* are metal pieces, which can slide along K, and serve as guiding pieces for the paper; *y y* are screws which keep the guiding pieces in the required position. To prevent the screws *y y* from slipping, the bolt *i* is placed across them. As often as a current is sent through the electromagnet E E, the latter attracts its armature, and the lever *h h* makes contact at *h*; as often as this happens, the pencil makes a mark on the paper at *d*. When the current lasts only a short time, a short line, technically called a dot, is produced; when the current lasts a longer time, a dash is produced.

The Morse Alphabet.—Combinations of dots and dashes give the different letters, numbers and signs, and thus form the Morse alphabet:—

A	B	C	D	E	F	G
·—	—···	·· ·	—··	·	·—·	——·

H	I	J	K	L	M	N
····	··	—·—·	—·—	——	— —	—·

O	P	Q	R	S	T	U
· ·	·····	··—·	· ··	···	—	··—

V	W	X	Y	Z	&
···—	·——	·—··	·· ··	··· ·	· ··

1	2	3	4	5
·——·	··—··	···—·	····—	———

6	7	8	9	0
······	——··	—····	—··—	———

Comma ,	Semicolon ;	Colon :	Colon Dash :—
·—·—	··· ··	—·— · ·	—·— ·—··

Period	.	..——..
Interrogation	?	—..—.
Exclamation	!	———.
Dash	—	—.. .—..
Hyphen	—	.... .—..
Pound Sterling	£	..... .—..
Shilling Mark	/	..— —
Dollars	$	... .—..
Pence	d.	—..
Capitalized Letter		.. . .—..
Colon followed by Quotation	: “	—.— ..—.
Cents	¢	.. .
Decimal Point	.	— .——
Paragraph	¶	————
Italics or Underline		..— .—..
Fractional Mark	—	.
Parenthesis	(	..... —.
	)	..... —.
Brackets	[	—... .—..
	]	—... .—..
Quotation Marks	“	.—. —.
	”	..—. —.
Quotation within a Quotation	“ ‘	..—. .—..
	’ ”	..—. .—..

The letters thus formed of dots and dashes are separated by variable spaces as they are called. There are three kinds of spaces: the space separating the elements of a letter, that separating the letters of a word, and that separating the words themselves. These durations of break or silence are as necessary as the durations of contact or sound. When we look upon the Morse alphabet as applicable to the various instruments described, including the sounder, we may define it as a method by which time is divided into multiples of an arbitrary standard or unit, viz., the dot.

1. A dash is equal to three dots.
2. The space between the elements of a letter is equal to one dot.
3. The space between the letters of a word is equal to three dots.
4. The space between two words is equal to six dots.

The letters in the alphabet most difficult to form are usually found to be J, K, B and V.

Familiarize the mind with these points. Physical perfection in the formation of the characters is acquired most easily when the mental dissection of the figure is complete.

(2) *Ink Writers.*—Thomas John, an Austrian engineer, constructed an ink writer for use at the central station of Vienna, in 1854, which was patented in Paris, and his modification of the Morse apparatus was then adopted by Digney and Company. Lewert and Siemens also constructed ink writers. Digney's ink writer, which is largely used in France, is shown in fig. 330. It is similar in construction to the apparatus just described, except that for the style is substituted a small metallic disc, which re-

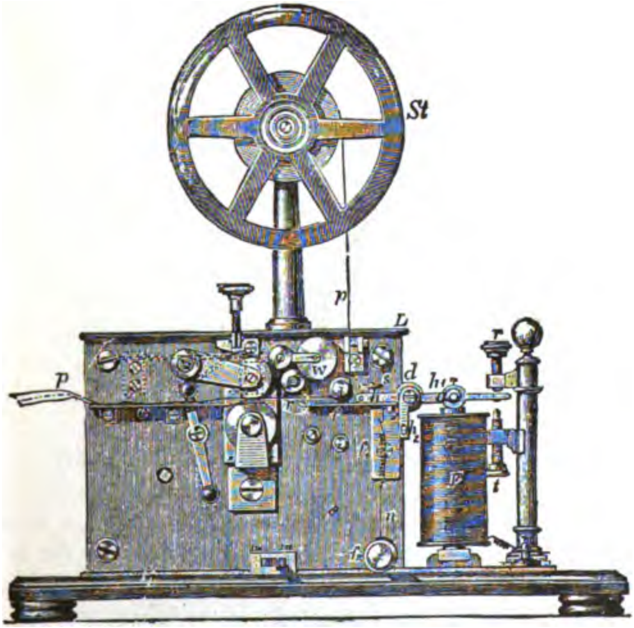


Fig. 330.—Digney's Ink Writer.

volves in ink. The electro-magnet E is in all respects the same as that of the embosser, except that its resistance is considerably greater. The lever $h\ h_1$, however, is differently constructed. At *a* it has an armature of a cylindrical shape, consisting of soft iron, which is slit open at its upper end; at *h* it has the spring *f*, and its axis of rotation *d* rests upon the piece h_2. The screws *r* and *t* limit the motion of the lever. The effect of the electro-magnet on the armature is regulated by the spiral spring f_1, which is connected by means of a string to the regulation screw f_2. Opposite the slightly bent end of the spring f_1 is the printing disc *r*, which comes in contact with the printing roller *w*. The strip of paper *p* is taken over the roller *i*, and passes between the printing disc *r* and the spring f_1. The position of the spring as regards the disc can be regulated by means of a screw. When a current passes through the electro-magnet E the latter attracts its armature *a*, lowers h_1, and by raising *h* the bent end of the spring f_1 presses the strip of paper *p p* against the disc *r*.

The electro-magnet in the ink writer by Lewert is made adjustable to either of two systems, namely, the system with constant current or that with transient current, and the lever consists of two movable portions connected with each other. In order that the need for this arrangement may be clearly understood, it is necessary to give the following explanation: Telegraph lines are worked in two different ways—viz., either with a working current, or with a constant current. In the first case the circuit is without current during certain intervals, and is "made" only when a signal has to be transmitted; in the latter case a current is always flowing through the circuit, and is interrupted at the required moment. If a line is to be worked both ways, the telegraph apparatus will have to be arranged so that the signs are produced in the same form with both methods. This is the purpose of the above-mentioned lever, which consists of two parts.

Fig. 331 represents a lever by V. Brabender. The spring *f*, which terminates in the prongs *c* and *g*, is fastened to the lever $h\ h_1\ h_2$ by means of a screw *e*. The position of the spring *e f* is regulated by the screw s; *a* is the armature of the electro-magnet. The writing lever proper *i b* is movable about *d*. The principal figure shows the regulation of the spring when a circuit is used, which is without current during certain intervals—that is to say, when not signalling. When the armature *a* is attracted by the electro-magnet it causes h_1 to make contact at *t* (fig. 330), and the arm of the lever *h* and *f g* to move upwards. As *i d* rests upon *g*, the end of the lever *i* will also be moved upwards —that is, it will press the strip of paper against the printing disc.

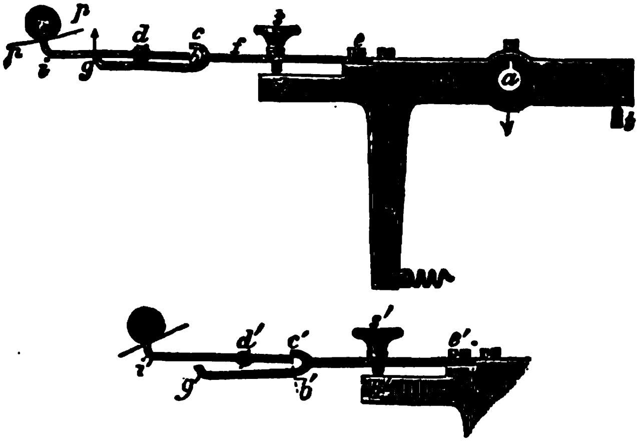


Fig. 331.—Brabender's Lever.

If, however, the screw *s* is tightened so that the spring *e f* is pressed down upon *h'*, as shown in the second part of the figure, the instrument is prepared to act with constant current broken only for the purpose of signalling. The writing lever, which is movable about *d'*, will be caught by the prong *c'*, and will lose contact with *g'*. The arm of the lever *d' i'* will be lowered, and the strip of paper will cease to make contact with the printing disc when the current is flowing, even though the attraction of the armature *a'* causes a moving upwards of *h'* in this case too. When the armature *a'* is not attracted—that is, when no current flows through the circuit—the lever-arm *h'* is lowered, and the prong *c'* presses the arm *d' b'* down, and *d' i'* up, so that the strip of paper is then pressed against the printing disc. To make the apparatus do for either method, it is only required to turn the screw *s* in the one or the other direction.

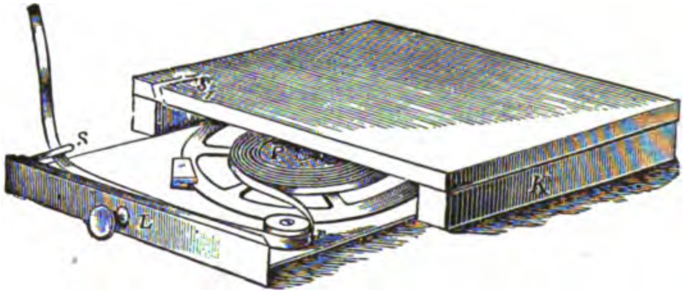


Fig. 332.—The Paper Wheel of the Ink Writer.

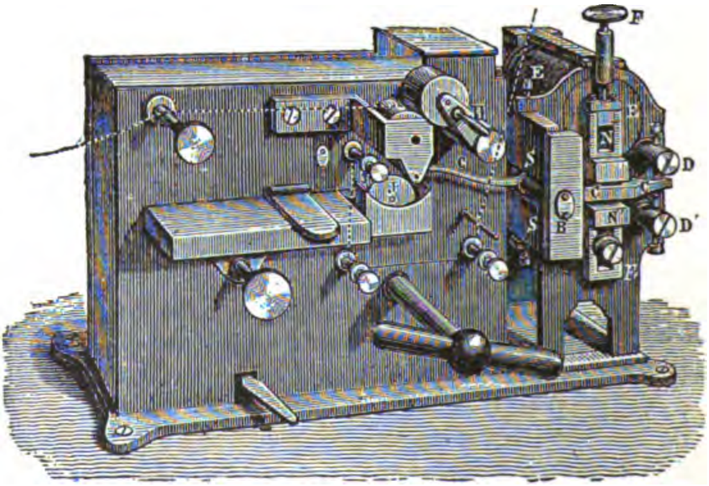


Fig. 333.—The Polarized Ink Writer.

In the ***normal ink writer*** the paper is arranged upon a horizontal wheel, as shown in fig. 332.

Polarized Ink Writers differ from ordinary ink writers in the construction of their electro-magnets and writing levers. The first apparatus of this kind was constructed by Siemens, and is shown in fig. 333. S S are south poles of a permanent magnet, which is connected at its other end with the iron cores of the electro-magnet E E, and gives north magnetism to them as long as the coils remain without current. The adjustable shoes N N′ have north magnetism, therefore, when the apparatus is at rest. One arm of the writing lever C C, which can move about B, consists of soft iron, and represents the armature of the magnet, being placed between these two poles. In consequence of its position it receives south magnetism by induction. The arm of the lever to the left carries the printing disc J. When the armature, whose motion is limited by the contact-screws D D′, is adjusted so that the two north poles affect it equally, it will remain exactly midway between the two poles; but if the slightest alteration is made in the attractive force of either pole, the armature will be moved in the corresponding direction. When a current passes through the coils of the electro-magnet, north magnetism is produced in one of its cores, and south magnetism in the other; but as both poles have north magnetism (for the magnet is permanent) it is evident that north magnetism will be strengthened in one of the cores, whilst either the north magnetism will be partially neutralized or else it will be wholly neutralized, and south magnetism will be produced in the other. The armature will, therefore, move towards the first pole; by this means the sensitiveness of the apparatus is greatly increased.

In order that this apparatus may be used with continuous currents, the shoe N is so arranged by means of the screw F, that it affects the armature more powerfully than the pole N′. The armature, therefore, makes contact at D; if now a current of corresponding direction be sent through the electro-magnet, the north magnetism of N′ will be increased, and the armature will move downward, and make contact at D′, thus pressing the printing disc against the strip of paper, and producing the desired sign. When the current is broken, the attractive force of N′ prevails, and the armature goes back again to D. The polarized ink writer may also be used with alternating currents, by causing the armature to be so arranged that both poles N and N′ affect it equally. When a current of a certain direction is sent through, the electro-magnet N′ is strengthened, and N weakened, so that the armature is pressed against D′, and the printing disc against the strip of paper. The armature remains in this position as long as the same current last. When a current is sent through in the opposite direction the apparatus N will be strengthened, and N′ will be weakened, and the armature will move towards D, and the strip of paper will lose contact with the printing disc.

VI. TYPE-PRINTERS.

Hughes' Type-printing Apparatus.—Fig. 334 represents a complete Hughes' type-printing apparatus, in which may be noticed a keyboard, a contact wheel, an electro-magnet, with an armature, connected with a rather complicated system of wheelwork, in front of which are the printing wheel and tape-roller. The messages are printed by this instrument in bold Roman type. The instruments at the sending and receiving stations are identically similar, and a current of short duration is required for each letter. The type wheels, which have the alphabet on their edges, are kept rotating synchronously. This synchronous movement of the corresponding pieces at the two stations is the principal difficulty of the instrument, and requires very accurate adjustment. There are twenty-eight black and white keys, which, with the exception of the first and sixth, counted from the left, are marked with letters, signs, and numbers. The contact arrangement D is fastened upon the table, and upon it rests the contact slide C, which rotates about the axis *a*. The contact slide is made by the clockwork to rotate with the same velocity as the printing wheel F, on the edge of which the letters, signs, and numbers are arranged in relief. The ink-roller K furnishes the wheel with the necessary printing-ink; a regulating wheel behind the type wheel corrects irregularities which might occur in the apparatus. To the left of the wheelwork is the magnet E, which loosens its armature *p*, and lifts the left arm of the lever *l*, when a current of the required direction and strength passes through its coils. The strip of paper is pressed against the lower edge of the type wheel by means of the printing roller M. The heavy fly-wheel V is used in order to make the machine move more regularly.

The receiver and the sender are united in one apparatus, and the receiving and sending stations use instruments that are identical as regards form, in order that the slide and the type wheel may be made to move synchronously at both stations. The mode in which the apparatus works is as follows: When a key is depressed, the lever connected with it raises a pin underneath the disc D; this pin projects from one of the rectangular openings which are made on the surface of the disc, and separates the two movable portions of which the slide C consists. When connection is made between the line battery and the line a current is sent into the leads, and thence to the apparatus of the receiving

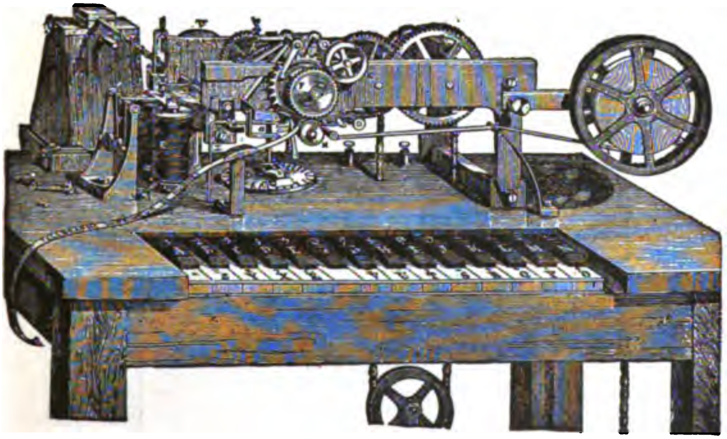


Fig. 334.—Hughes' Type-printing Telegraph.

station, where it flows into the coils of the electro-magnet. When there is no current the magnet holds the armature *p* attracted; but the arriving current neutralizes the magnetism of the electro, and the armature moves up; this affects the lever *l*, which, in its turn, starts the printing arrangement. If, for instance, the key upon which the letter A is printed is depressed at

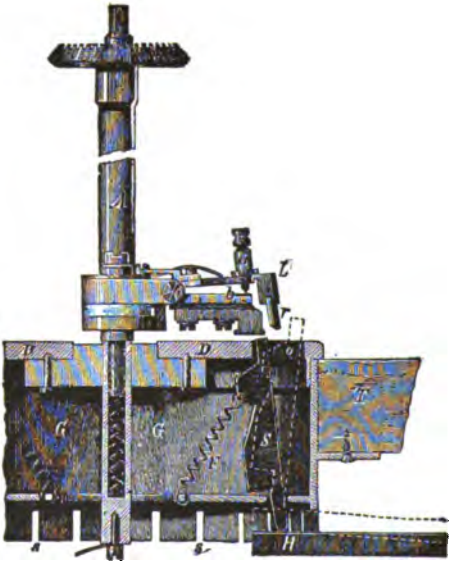


Fig. 335.—Current Arrangement in Hughes' Apparatus.

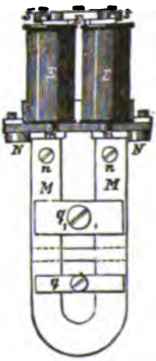


Fig. 336.
The Magnet.

the sending station, a current arrives at the receiving station when the letter A is opposite the printing roller M. The current is only able to flow through the leads to the receiving apparatus at this moment because the slides move synchronously with the type wheels, and the closing of the circuit can only take place at the moment when the slide moves over the opening of the disc D, which corresponds to key A. When the armature *p* is lifted at the receiving station, it raises the lever, and causes the printing roller M to press the paper strip against the type wheel, and produce the letter A.

We have yet to show more clearly how it is that the current flows only when a particular letter is passing the connection with a particular key. The arrangement of the pin case, and the slide with its contact arrangement, are shown in fig. 335. D D represents a section of the disc fastened to the table T, and showing one of the rectangular openings *o*, each of which corresponds to a key. The disc D D forms the cover of the case G G, which has slits *s s* cut on its lower side. The levers connected with the different keys project through these slits. The lower ends of the pins S rest upon the levers, so that their upper ends are inserted into the openings *o* (indicated by the dotted lines) when the key is pressed down. The axis of rotation A of L passes through the centre of the disc D D, and is connected with the wheelwork of the type wheel by means of cog-wheels. When L arrives at an opening *o*, the pin S, which is made to project from *o* by depressing a key, raises *r*, and by this means breaks contact between *a* and *b*. The leads from the battery are so arranged that when L has this position connection is made with the line, and the current flows to the receiving station.

When the current arrives at the station it has to demagnetize the magnet. In order to facilitate this demagnetization, Hughes constructed a magnet like that shown in fig. 336. It consisted of a permanent horse-shoe magnet M M, and the electro-magnet E E. The former consisted of four steel plates in horse-shoe form, which were held together by the screws N N, and the brass cross-pieces q q_1. The cores of the electro-magnet consisted of hollow wrought-iron cylinders, which were placed upon the poles of the permanent magnet; wire was coiled round these hollow cores, and they were then covered at both top and bottom with brass plates, in order to protect the coils. The resistance of the electro-magnet coils is 1,200 Siemens' units. Over the shoes of the magnet is placed the armature E_1. Even when the coils are without current the iron cores possess a certain magnetic force in consequence of their connection with the permanent magnet.

The spring affecting the armature is so regulated as to be weaker than the magnetic force of attraction, so that the armature remains on the shoes of the electro-magnet; but when a current of the proper strength flows through the coils the attraction of the magnet is neutralized, and the spring draws the armature off.

The Exchange Telegraph Company's System.—Another special system of telegraphy is that of the Exchange Telegraph Company of London, which disseminates news from a central office to a large number of subscribers (at present about 750) scattered over the metropolis. The company is authorized to carry out its operations by a special license granted by the Postmaster-General, on the 28th of March, 1872. The license describes the aim of the company as to carry out a system of exchange by telegraph, in which identical information is supplied from certain central stations or from certain determined points to any number of subscribers, by means of an automatic printing apparatus, which neither requires the use of local batteries, nor of clockwork, nor the presence of an attendant, nor necessitates any knowledge of telegraphy on the part of the subscribers.

A number of wires radiate from the central office, and each wire passes in zigzag form through a district in which there are subscribers, and is finally put to earth. The wires are tapped as they pass the clubs, hotels, or other institutions which have become connected with the company, and the printing instruments inserted so that all the printing instruments of any one district are joined in series. Each wire has its own battery at the central office, the number of cells being varied according to the amount of work with which the wire is charged, that is to say, according to the number of instruments it contains. This number varies in the different districts from six or eight to fifty. Each battery is brought into action by means of a relay, and there are, therefore, as many relays working simultaneously as there are lines or batteries. The central office is also a general telegraph station, but the clerk who sits at the table, instead of writing out the message, reads it off from the tape of the Morse instrument as it unrolls itself before him, and, as he reads it, transmits the message to all the receiving instruments. During our visit to the central office at 17 and 18 Cornhill, a message from a correspondent began to appear on the Morse ink writer in less than one minute after it was handed in at a distant town, and at the same instant it was transmitted to all the receiving instruments of the company, and printed by them as fast as the Morse ink writer delivered it. A controlling instrument exactly similar to those of the subscribers stands in the central office, and supplies the home record of what is transmitted. On an average each instrument prints nearly 5,000 words a day, but on some days, when news is plentiful, as many as 15,000 words are transmitted.

We may mention at the outset that there are three kinds of messages supplied by the company, and each kind requires its own central office, its own form of receiving instrument, and an independent installation. Financial messages are printed from type-wheels, containing not only the letters of the alphabet, but also numbers, fractions, and signs. The second class of messages consists of short pieces of news that are printed in bold type on strips, that may be detached and pinned to the notice-board of a club or hotel. The type-wheels for these contain no fractions, and therefore work at a greater speed. The third class of messages consists of general news. The type-wheels in the instruments of this class need not contain figures, and are so light as to make a very high speed of transmission possible. Indeed, by an arrangement of the letters and a reduplication of *e* and *h* (the letters which occur most frequently), the speed of transmission now attainable with these instruments is greater than that with which the sending clerk can manipulate the sending apparatus. The currents supplied to the receivers first cause the type-wheels to revolve until the letter that is wanted is opposite to the tape, and then they stop it and bring the paper up to it so as to print the letter. Finally, they jerk the tape forward ready for the next letter. The wires leading to the instruments of the financial or first system are double, one wire conveying the current which turns the wheel, and the other the current which presses the tape against the letter. But in the case of the lighter instruments, Mr. F. Higgins has invented a method of effecting the double action with a single wire. For this purpose he introduces another small magnet which operates a contact-maker. This diverts the current from the type-propeller to the printing mechanism whenever a pause takes place in the rapid reciprocal currents which are transmitted to revolve the type-wheel. The effect is the same as that secured in the larger instruments with the double wire.

The subscribers of the first class receive at their own offices through the day the course of exchange and state of the markets within a minute of their being officially stated at the Exchange; and no doubt this work, being the first undertaken by the company, gave to it its name.

We are now in a position to examine in detail the instruments used in carrying out the system. These are the transmitter, or sending apparatus; the receiver, or printing apparatus; the relay, and the battery.

The *transmitter* is the apparatus by which the sending clerk produces the "making" and "breaking" of the circuit which are transmitted to the relays, and thence to the receivers in order to effect the impression. It consists of a revolving cylinder or commutator worked by an electric motor, and commanded by a pianoforte key-board, like the key-board of Hughes' apparatus (fig. 334). This commutator is composed of a shaft or cylinder, on which is fixed a series of spurs or teeth arranged in the form of a helix, and turning in front of the inner extremities of the levers attached to the keys. When the clerk depresses one of these keys the corresponding spur is caught, and the revolving commutator is detached from the electric motor that works it. At the same moment a collar attached to the spur closes the printing circuit. When the key is released the printing circuit is at first broken, and an instant after the shaft again begins to revolve.

The motor is a simple magneto-electric motor supplied by a battery of potassic bichromate elements. The speed of the motor

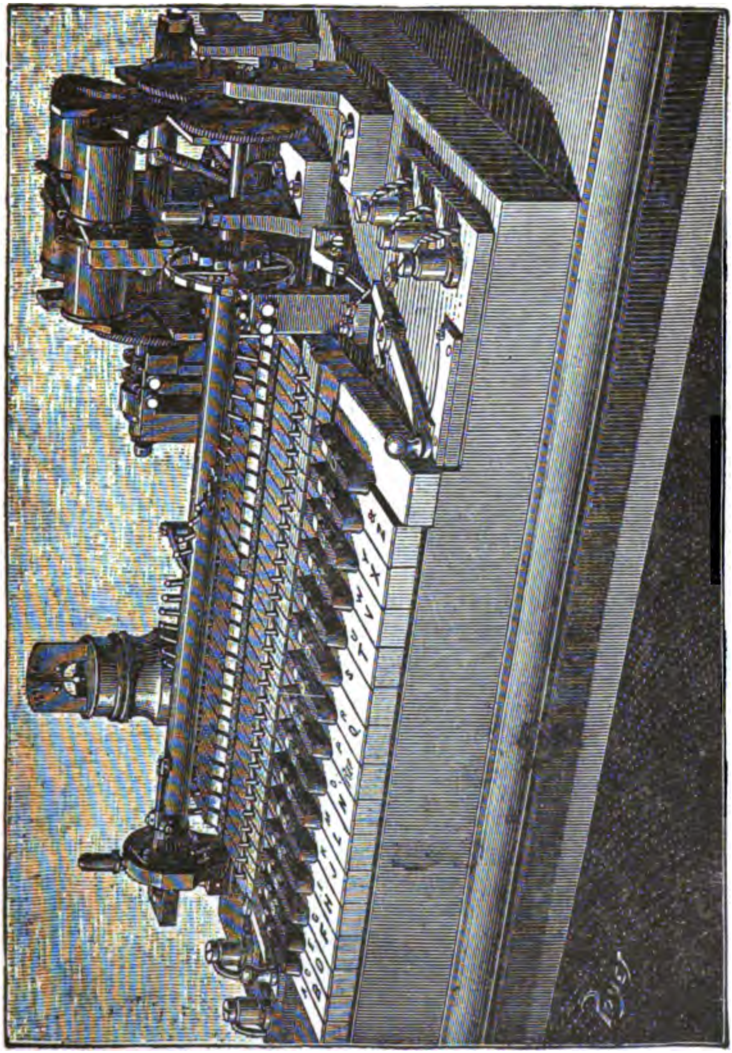


Fig. 337.—Transmitter of the Exchange Company's Apparatus.

is regulated by the aid of a centrifugal governor which breaks the current when the speed reaches the rate which is intended to be the maximum. It is very sensitive to the smallest variations in the rate of rotation, and keeps the speed practically uniform. The governor can, however, be regulated to suit different systems and to allow of different maximum speeds.

This transmitter would easily work eighteen hundred receivers, and actually, at the present time, does work over five hundred.

The transmitter is furnished with a galvanoscope, which shows when a current passes, and two switches, one commanding the electric motor, and the other the relays. When the two switches are turned on the motor works, the cylinder turns, the relays close the circuits, and the type-wheels of all the receivers revolve synchronously with the cylinder of the transmitter. When, by depressing a key, the cylinder is stopped by the operator in a certain position, all the currents are simultaneously interrupted and all the type-wheels stop in the same position as the cylinder. It is at this instant that the current passes in the second wire and causes the attraction of an armature, which lifts the tape of paper against the wheel so as to produce the impression.

The Relays.—It would be difficult to transmit and to regulate the currents supplied to the various lines if they were emitted directly from the same battery, and therefore a separate battery, connected by means of a relay, is used for every line. This plan makes it easy to localize and remedy any interruption to the working that may occur. The contacts made by the transmitter act only on two distinct circuits, each of which consists of a number of relays, the electro-magnets of which are joined up in series. One group of relays commands the rotation of the type-wheels, and the other commands the printers or armatures that press the type-wheels against the tapes.

Fig. 338 represents one of these relays half-size. It consists of two short electro-magnets placed vertically, and having a horizontal armature which turns on a pivot at the end. The armature is held back by a spring, the tension of which is carefully regulated, so as to give it but little play. When the transmitter sends a current through the relays, the armature is drawn down and closes the battery contact of the corresponding line by bringing together two copper points, one of which is fixed, and the other carried by the armature itself. The cores of the magnet are short, split, soft iron tubes, which admit of being successively magnetized and demagnetized with great rapidity. The line is discharged by means of a condenser to prevent sparking.

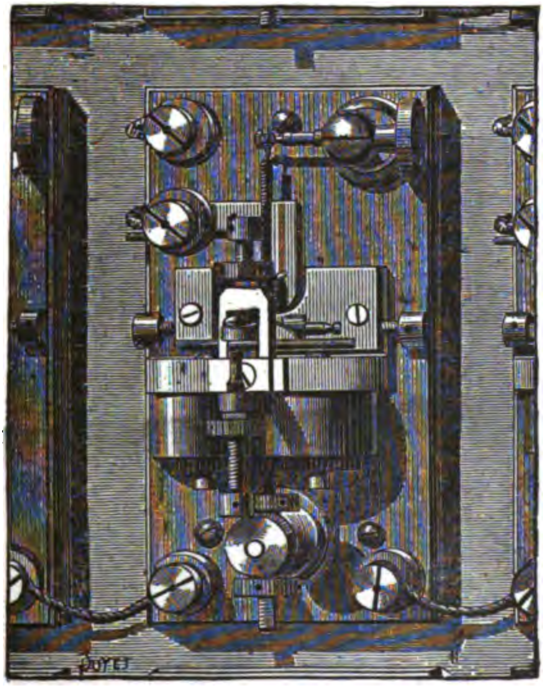


Fig. 338.—The Relay.

The Receiver or Automatic Printing Instrument.—We have already pointed out that there are three forms of receivers in use, differing in size and speed of working. The instrument for printing general news is the smallest, and is, in fact, rather smaller than an ordinary Morse embosser. The receiver for the

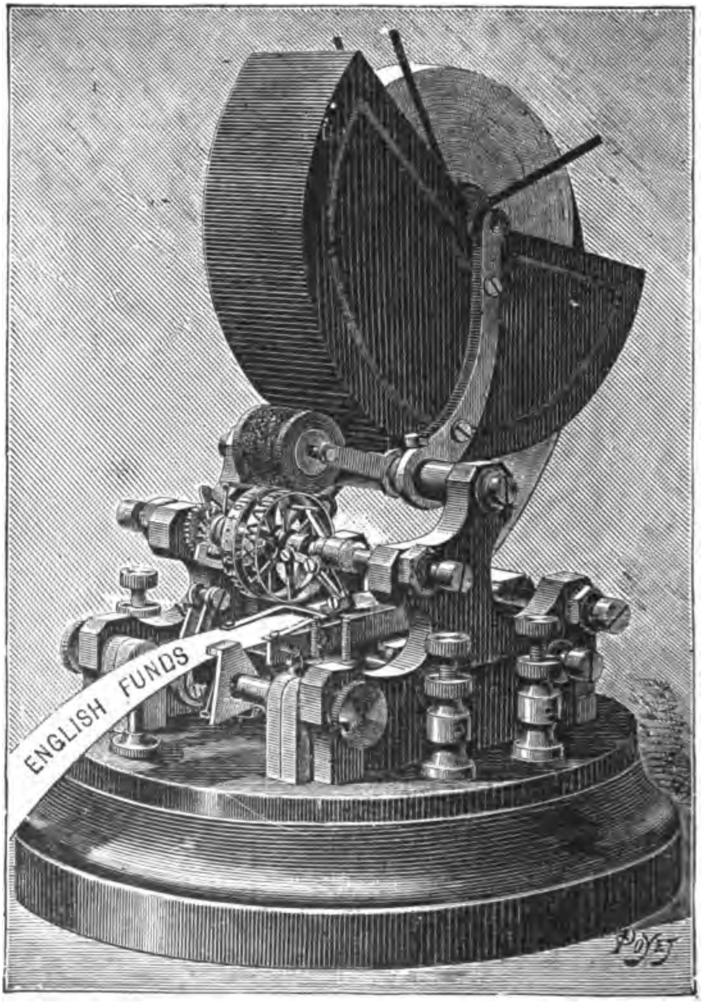


Fig. 339.—The Receiving Instrument.

financial system is represented in fig. 339. It has two type-wheels, each of which can take up two distinct positions by sliding lengthwise on an axle which also carries an escapement-wheel having teeth of a particular form. A clutch at the end of a lever, attached to the armature of an electro-magnet, restrains or liberates the escapement-wheel as the armature oscillates under the action of the electro-magnet. Each type-wheel carries on its edge twenty-eight characters and two blank spaces. One wheel has all the letters, and the other the figures and punctuation stops that have to be printed—there being sixty signs in all. The attraction of the armature under the influence of a single emission of current makes the type-wheel turn through the space of one letter; the return of the armature under the action of a counteracting spring at the instant of the ceasing of the current also causes the wheels to advance another letter. Fifteen emissions of current, therefore, give to the type-wheel a complete revolution. The operator can produce any impression he likes with either of the wheels by first causing it to stop on one of the blanks, and then bringing into action the printing system commanded by the second circuit. In this position of the wheel the printing lever acts on a special mechanical arrangement which moves the type-wheels lengthwise in one direction or the other, so as to bring either the letter-wheel or the figure-wheel above the strip of paper. This motion of the wheels on the axis can only be produced when the wheels are stopped on one of the blanks. The printing apparatus commanded by the second circuit raises the paper against the wheel above it, so as to print the letter or figure, and then jerks it forward by means of a grip so as to space off the next letter. All the motions necessary to produce the impressions are thus produced by two electro-magnets worked by two distinct circuits without any mechanism resembling clockwork.

The instruments of the second and third class, having single type-wheels, are simpler in their action than that of the first class, which is represented in the figure.

It is now easy to understand the general working of the system. Let us, for the moment, confine our attention to the line traversing one district, and dispense with the relay, supposing the contacts to be produced and the currents forwarded by the transmitter directly. This simplification does not change the principle of action, for the object of the relays is only to multiply the contacts and the number of lines and instruments controlled by one operator.

The motion of the revolving commutator causes the circuits to be alternately made and broken, and short currents to be in consequence sent to the receivers. Here these currents give periodic impulses to the clutch which catches the toothed wheel attached to the type-wheel. The result is that the type-wheel of the receiver and commutator of the transmitter revolve synchronously. When the commutator stops the type-wheel stops in the same position. If at this instant the second or printing circuit be closed by the operator, the current that flows lifts the printer and impresses the corresponding letter on the tape. When the operator releases the key the commutator and the type-wheel revolve again until another key is depressed or the switch turned off.

We have not space to notice the many ingenious details that have been devised by the inventor and engineer of the company for securing absolute regularity and synchronism in all the instruments. By a very ingenious device of Mr. Higgins, the inventor, the wheel of every receiver sets itself at zero when the current is first started. If, therefore, by accident or intention a type-wheel be turned out of unison, so to speak, with the transmitter, immediately the current starts the wheel comes automatically back to zero. The receivers require but little attention beyond the occasional renewal of the tapes. The engineer at the central office has everything so entirely under control that he can detect and localize any defect in a very few minutes, and has at hand the means of promptly remedying it. On the whole, the work of this company is one of the most useful, as well as one of the most interesting products of the fruitful alliance of mechanical science with electricity.

CONNECTIONS AND AUXILIARY APPARATUS.

Relay Apparatus.—As a current which comes from a distance is often so weak that it is insufficient to work the electro-magnet that marks the paper, the relay is used, and a strong current is sent from a local battery through the receiving instrument. *The relay is a delicate form of electro-magnet, resembling the sounder, but having for object simply the closing of a contact, so as to bring a local battery into play.* A great many different relays have been constructed, but they all may, however, be grouped into two classes, namely, polarized and non-polarized relays. The former are more frequently used in England than the latter, and are so called because their armatures are polarized either by means of permanent magnets near them, or by being themselves the poles of permanent magnets. One of the oldest non-polarized American relays is shown in fig. 340. The brass plate *a a* is fastened upon the block A A, and carries the electro-magnets E E, the iron cores of which are connected with each other by means of the iron piece *m*. The bearings for the lever *c*, with its armature K, are attached to the pillar *b*. The motion of this lever is limited by the contact screws *e f*, fastened to the support *d*, which is insulated and fixed upon *a a*. The spiral spring h_1, the tension of which can be regulated by means of the guiding piece g_1

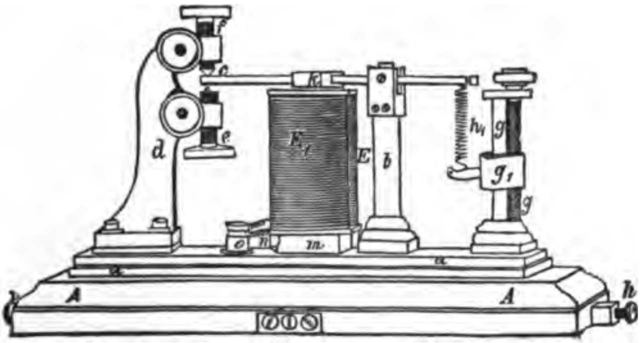


Fig. 340.—American Relay.

moving upon *g g*, keeps K from being attracted. The support *g g* is connected with the binding screw *h*; and screw *e*, which has a contact pin at the upper end towards the lever *c*, is connected with the second binding screw *i*. The screw *c* is mounted with ivory, and therefore does not influence the current. The local circuit, which contains the local battery and the writing apparatus, is closed at *i* and *h*. When even a very weak line current passes through the coils of the electro-magnet E E_1, it will cause it to attract K, and contact will be made between *c* and *e*.

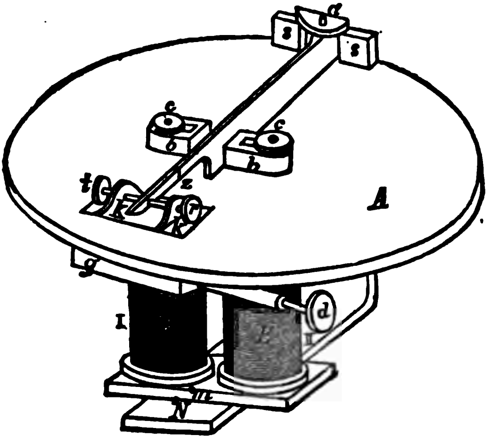


Fig. 341.—Polarized Relay.

The current from the local battery reaches the support *g* through *h*, flows through spring h_1, the lever *c*, and screw *e c*, from there through *d* and *i*, and so into the writing apparatus. As every line current which reaches the relay acts in the way described above, it is evident that the relay sends a powerful local current instead of the weak line current into the writing apparatus, and thus produces a distinct writing, no matter whether the sending station be at a short or long distance.

Siemens' Polarized Relay.—A polarized relay by Siemens is shown in fig. 341. Down the side of the instrument and bent underneath it passes the hard steel permanent magnet S N, the upper or S end of which is slit so that a soft iron lever can be pivoted in the slit at *a*. Upon the horizontal arm of the permanent magnet, which is bent at right angles, the electro-magnet E E is placed, and connected by means of the iron piece *m*. The cores, which pass through the plate A, have movable shoes *b b*, which are kept in the desired position by means of the screws *c c*. The armature is represented by the lever Z, pivoted at *a* between the south poles S S of the permanent magnet. The play of the lever is horizontal from side to side, and is limited by the contact screws *r t*, one of which ends in an agate point, and the other is insulated by means of the gutta-percha pieces K K, and can be adjusted by means of the screw *t*. The electro-magnet E E being placed upon the north pole N of the permanent magnet, the poles *b b* have north magnetism, whilst Z has south magnetism. The one or the other pole may be made to prevail by adjusting the lever. The action is therefore as follows: The pole N of the permanent magnet N S induces south polarity in the bar *m* and the ends of the cores next it, and therefore causes north polarity in the ends of the cores remote from it. Again, the pole S S induces north polarity in the end *a* of the lever *a z*, which is pivoted to it, and south polarity in the end which moves between the poles *b b*. The continuation of this lever beyond *z* is a non-magnetic metal, which is not affected by N S. When the lever *a z* is equally attracted by both poles at *b* and *b*, it remains equidistant from them, but when the pole is screwed a little nearer than the other it draws the lever to it. When the relay is at rest this is its position, the lever then touching the agate point. When the line current enters the coils of the electro-magnets E E the poles are changed, that at the end *b* of II being strengthened as a north pole, and that at the end *b* of I being either weakened or reversed to a south pole. Hence the lever is drawn from the agate point to the opposite metal point *t*, and remains in contact as long as the line current flows, but falls away when this current ceases. The contact closes the local circuit which works the instrument. The polarized relay by Siemens has a resistance of 1,200 Siemens' units.

Lightning Plates.—For the completion of a so-called Morse's system, besides the apparatus described, a galvanoscope and some arrangement for protection against lightning are required. The galvanoscope is used to indicate the presence or absence of a current in the circuit, the direction of the current, a test as to whether the apparatus is properly joined, and the presence of any faults in the line. Leads that are on the outside of buildings have to be protected against lightning; that is, every lead has to

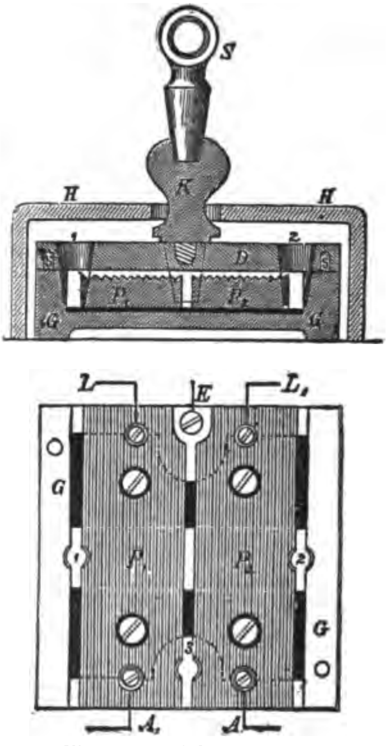


Fig. 342.—Lightning Plates.

be connected with a lightning conductor. This is necessary both for the protection of persons employed, and also for that of the apparatus. Different forms have been given to these lightning conductors. Bréguet's, for instance, consists of brass plates, the toothed edges of which come very close to each other, so that the interval can be leaped over by currents of high potential, but not by an ordinary working current. The plates by Siemens and Halske, shown in fig. 342, are very largely used at the present time. Two cast-iron plates P_1 P_2 are fastened upon the cast-iron ground frame G G, being grooved on their surfaces, and insulated by means of india-rubber plates. Opposite P_1 P_2 is placed the grooved cast-iron plate D; a distance of about 0.5 millimetre is left between the grooves of the former and the latter; *s s* are steel pins, which fit in the holes of plate D; D and G are connected with the earth-leads E; plate P_1 is connected with a line L and apparatus A, and plate P_2 is connected with line L_1 and A_1. The current coming, for instance, from the line L_1 will flow through the plate P_2 and then through A_1 to the apparatus, and from thence to earth, or through A, plate P, and the line L to the next station. Atmospheric electricity arriving from L_1, however, will take the shorter way; that is, through plate P_2 and D, and then to earth.

Siemens' plate may also be used for changing the line connections. For this purpose the holes 1, 2 and 3 are bored in it, and fitted with the plug S; but under ordinary circumstances, S is inserted in the wooden knob K. When S is inserted in bore 1, plate P_1 is connected with D; *i. e.* lines L and A are connected with the earth; the same happens with L_1 and A_1 by inserting S into 2. By inserting S into 3, P_1 and P_2 are connected with each other, or (which comes to the same thing) with L and L_1, so that their own station apparatus is excluded. The apparatus just described is, as a rule, covered with a wooden case H H, which is screwed to the table. The case has only one opening, which is opposite the hole 3.

Connections.—In order that the mode of action of the Morse system, when completed with all necessary connections, may be understood, we shall now proceed to consider the connection of the several portions of the apparatus with each other, and also with the apparatus of another station, etc.

Fig. 343 shows the connection of a Morse system with relays, worked by single currents. The lightning apparatus and galvanoscope are here left out. M and *m* indicate the Morse keys, O *o* sending contacts, P *p* receiving contacts, R *r* the magnets of the relays, N *n* contact levers of the relays, R_1 r_1 the electro-magnets of the writing apparatus, C Z and *c z* sending batteries, C_1 Z_1 and c_1 z_1 local batteries of both stations going. When no signalling is on, the stations are connected by means of the line L and

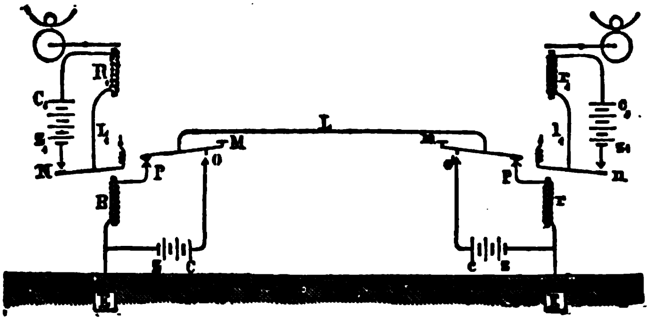


Fig. 343.—Morse Connections.

earth-lead E E. When one station wishes to send a telegram to another, the following circuit can be closed by pressing down the key M upon O, so as to close the contact at O, and at the same time to open the contact at P: From one pole C of the sending battery, the current flows over O M through the line into the second station, thence it proceeds over *m p* into the electro-magnet *r* of the relay, and so to earth. The other battery pole Z of the sending station is also connected with earth. The electro-magnet *r* attracts its armature, contact is made at *n*, and the local circuit of the receiving station closed. The current now flows from one pole z_1 of the local battery over n_1, through the line l_1 into the electro-magnet r_1 of the writing apparatus, hence it proceeds to the second pole c_1 and so back to the local battery. The magnet of the writing apparatus attracts its armature, presses the pencil or printing wheel against the strip of paper, and reproduces the sign given by the key M.

Ink writers are, however, more frequently used without relays. In this case the ink writer is substituted for the relay and local battery, but otherwise the figure serves for both cases.

The connection of an end station by means of a relay is shown in fig. 344. G represents a galvanoscope, and B a lightning plate.

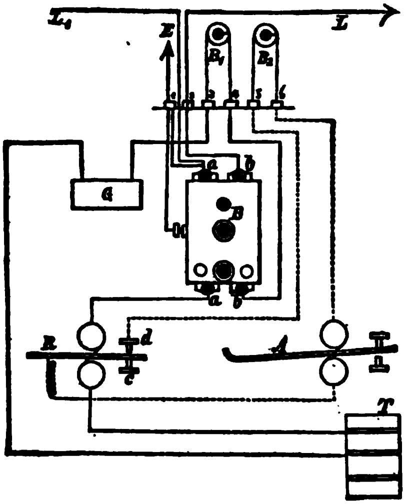


Fig. 344.—A Morse End Station.

The current arriving from L flows over 2 into the plate *b b* of B through the battery B$_1$ and the galvanometer G, and then through the key T, which is connected with the electro-magnet of the relay; it then flows through the plate *a a* of the lightning conductor over 1 to earth. When the current is interrupted the spring R of the relay takes off the lever from the contact *c*, and makes contact at *d*, and thus the local circuit is closed as follows: The current flows from the local battery B$_2$ over 5 to *d*, through R into the writing apparatus A, and from here over 6 and back to the battery. For every interruption of current in the circuit a sign is produced in the writing apparatus of the end station. If the station is an intermediate one, and not an end station, the connection has to be slightly altered; this alteration is indicated by the thin lines in fig. 344. The change is as follows: The plate *a* of the lightning plate is not connected by means of 1 to the earth-leads, but is joined to the line L_1.

Intermediate and Terminal Stations.—Arrangements are sometimes used to send on telegrams through an intermediate station to the end stations automatically, when the distance between the sending and receiving stations is considerable. The arrangements have to be different for the Morse, the Hughes, and the self-acting apparatus. For the Morse apparatus the connection is shown in fig. 345. The lines L_1 L_2 are connected by the clamps 2 and 3 to the relay levers h_1 and h_2 at the intermediate station. The contact r_1 is connected with the electro-magnet R_2, and the contact r_2 with the electro-magnet R_1. The contacts t_1 and t_2 are usually connected with one and the same battery B. If, however, the resistances in the lines differ very much, a more powerful current is used for the larger resistance than for the smaller. A telegram arriving, for instance, through L_1 is transmitted in the following manner: The currents from L_1 enter at 2, flow over h_1 to r_1, through the coils of the electro-magnet R_2 and then over E_2 to earth. In their passage these currents act on the relay and bring into play the battery B at the intermediate station, for R_2 attracts its armature, and causes the lever h_2 to make contact with t_2. Now, as one pole of battery B is connected to earth by means of 4, when the contact t_2 is closed by the relay the current flows from the second pole over 5, t_2, the lever h_2, and thence over 3, to the line L_2. A similar action takes place when the sending occurs in the other direction. A current coming from L_2 flows over 3, h_2, r_2, R_1, E_1, to earth, whereby h_1 is caused to make contact with t_1 and a current is sent from battery B over 5, t_1, h_1, and 2, into line L_1.

Fig. 346 shows the connection of apparatus for a station which is to be used either as an intermediate or as an end station. k_1

and k_2 indicate the commutators with their contacts a_1 b_1 and a_2 b_2: T_1 and T_2 are Morse keys. By pushing the two handles to the right so that k_1 makes contact with b_1, and k_2 with b_2, the station is connected as an intermediate station. If, for instance, a current arrives from L_1 it will flow over 2 k_1 b_1 h_1 r_1, to the contacts of key T_2, then through the electro-magnet R_2, over 1 to earth at E. The relay is by this means brought into play, and the lever h_2 makes contact at t_2, sending the current of battery B over 5 t_2 h_2 b_2 k_2 and 3 to line L_2. When the handles are pushed to the left a current arriving from L_2 flows over 3 k_2 a_2 T_2, into the coils of the electro-magnet R_2, and from here over 1 to earth

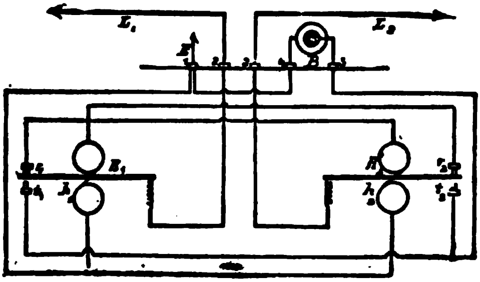


Fig. 345.—Connection of Intermediate Station.

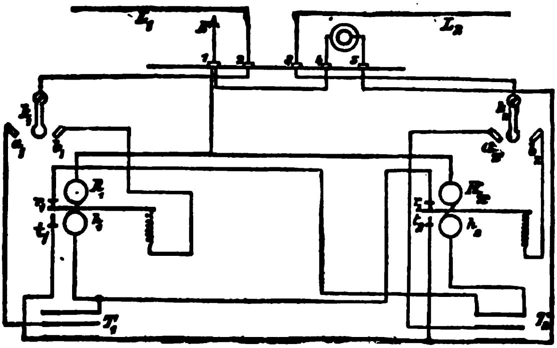


Fig. 346.—A General Station.

E. Although the lever h_2 makes contact with t_2 the battery is not connected with line L_1 or L_2, as may be seen from the figure, and therefore the station acts as a terminal receiving station. We need hardly mention that polarized relays may be advantageously used for transmission in all these cases.

It would not be advisable to employ the Hughes apparatus at the intermediate station in the same manner as the Morse apparatus is connected, first, because the Hughes apparatus is too expensive; and, secondly, because it would be necessary to employ four Hughes instruments, which would have to be made to move synchronously. Many proposals have been made for transmission on to a Hughes apparatus, but we need only describe one of them, namely, the arrangement shown in fig. 347.

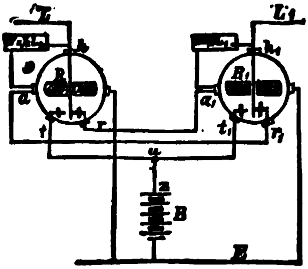


Fig. 347.—Connection for the Hughes Apparatus.

R and R_1 represent Siemens' polarized relays, r r_1 and t t_1 being their contacts. The lines L L_1 are joined to the relay levers at h and h_1, and are connected with the electro-magnet through a and a_1. W and W_1 are inserted resistances; a is further connected with the contact r_1, and a_1 with the contact r. The contacts t and t_1 are connected with the zinc pole of battery B. The second ends of the wires of the electro-magnet are joined to the earth-leads E. As the resistance W is equal to half the resistance of line L, and resistance W_1 to half the resistance of L_1, the resistance which the circuit offers to the electro-magnet of the relay R is equal to $\frac{3}{2}$ of the resistance of L, and the resistance which it offers to the electro-magnet of R_1 is equal to $\frac{3}{2}$ of the resistance of L_1. When a current passes through the line L_1 to the intermediate station, it flows in the following directions: The line current divides at h_1 into two portions, the larger of which flows through the rod which offers it the least resistance, that is, over r_1 or through the coils of the electro-magnet R, and then to earth

E; the weaker portion flows from h_1 through the resistance W_1, until it reaches a_1; here it divides again—one branch flows from a_1 through the coils of R_1, and then to earth; the other flows from a_1 over r and h to the line L. The strongest of these three branch currents, that is, the one over r_1, reaches the coils of the electro-magnet R, and causes the lever of R to make contact with t, thus making the passage of the current of battery B as follows: From u, over t, through the lever of the relay to h, and then to the line L; no resistance being inserted here, the greater portion of the battery current will flow to the Hughes apparatus at the end station. As h is connected with a, a branch current will also take this course, but in consequence of the inserted resistance at W, will only be a very weak one. This branch current again divides at a, one part flowing through the coils of R to earth, whilst the other part flows over r_1 and h_1 as counter current into the line L, and from there to the Hughes apparatus. The electro-magnet R is, therefore, influenced by two currents, one coming through L_1 h_1 r_1, namely, the line current; the other coming from B over u t h W and a, namely, the battery current. The latter circulates through the coils of the electro-magnet at the very moment when the former causes the lever of R to make contact. The first current having the direction opposite to that of the latter, it follows that the battery current will cause the lever of the relay R to be brought back again upon the contact r. When the Hughes apparatus is used it is necessary to employ the opposition current, which will force back the armature at the required moment into its first position; that is to say, the position of rest.

Calls and Alarms.—To signal from one station to another, bells, as a rule, are used. These bells are generally similar to those hereafter described when we are considering the telephone installations. Fig. 348 represents a simple and common form of bell, the hammer of which is attached to the armature of an electro-magnet. The current enters the screw a, flows through the coils of the electro-magnet M M, and passes to the screw d and spring f, which carries the armature A; from f

the current flows through the contact pin *c* to the second pole-clamp *b*. The armature is attracted by the magnet, and the arm B with its hammer K strikes against the bell G; whenever this happens the contact is broken between *c* and *f*, and the armature returns to its original position and makes contact again.

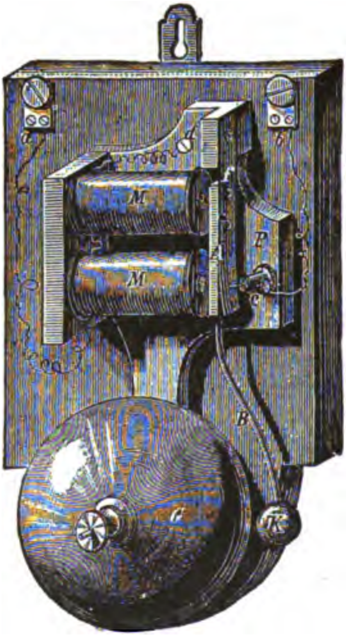


Fig. 348.—Electric Bell.

Telegraph Leads.—Many of the arrangements and precautions which we shall describe in connection with telephone installations are applicable to telegraph lines, except that it is not so necessary to provide against the induction of parallel wires. Telegraph lines are open and overlaid (*i. e.*, overhead wires), or covered and underlaid (subterranean and submarine).

An open line of telegraph requires supports, wires and insulators. Supports may be of wood or iron. In England, however, wood is employed chiefly, because it is three times as cheap as iron, and is a better insulator when dry. The wood generally used is either native-grown larch or Scotch fir. To prevent decay the wood is usually seasoned and dressed, or pickled. The seasoning is for the purpose of getting rid of the sap, and is effected best by exposure to free currents of air. The means used for the preservation of timber may be applied externally or internally.

Charring and tarring are external applications. The charring consists in roasting the butt-end of the pole over a slow fire.

The tarring coats the thick end with a mixture of three parts of Stockholm tar, seven parts of gas-tar well boiled, and three parts of slaked lime. Wood is *kyanized* by impregnating it with certain metallic salts, such as corrosive sublimate (perchloride of mercury). Chloride of zinc, and copper sulphate, have also been used in a similar way, and the three methods have been named after their respective discoverers, Kyan, Burnet, and Boucher.

Another useful application is creosote, an oily coal-tar product formed in the distillation of coal. It is prophylactic and antiseptic, preventing disease and destroying the germs of animal life, besides which, when forced into the pores of the dried wood, it makes it impervious to moisture. Of all the processes for the preservation of timber, creosoting has given the most universal satisfaction.

The Wires.—Iron is the material employed in open telegraph lines. Copper, though a better conductor than iron, is not so good for suspended lines, as it stretches, soon loses its elasticity, and is much affected by temperature. The wire in general use for all through-circuits is No. 8 (diameter .170 inch). No. 11 (diameter .125 inch) is used for short circuits of minor importance. Iron wire ought to be covered with a coating of zinc (galvanizing).

Insulators.—Glass possesses high resistance to the passage of electricity, and has a smooth, hard surface; but it condenses the moisture from the air on the surface, so as to destroy the insulation, and is very brittle. Ebonite offers a very high resistance and is strong, but its surface deteriorates rapidly, becoming cracked and fissured, so as to retain both dirt and moisture. Earthenware is the material from which most of the insulators are made, the better kinds being of glazed porcelain, the commoner of glazed brown pottery ware. The form given to these is usually that of an inverted cup or bell. The most perfect form of insulator will be that in which the surface exposed is a minimum, and the wire is as far as it can be from the main support. That which is in most general use in England is the insulator of Mr. C. F. Varley. It is made in porcelain and also in brown earthenware, and is shown in fig. 349. It consists of two distinct and separate inverted cups (*a* and *b*), fitted into each other by cement. The inner cup screws into the outer, and is cemented to an iron stem *c*, which serves as a bolt to fix it to the cross-bar or arm *d*. The wire is placed in the groove of the insulator and very tightly bound to it. The two cups have recently been made in one by being united at the upper end. Another insulator, lately introduced by Messrs. Johnson and Phillips, is an inverted porcelain bell curved inwards at the bottom so as to form a ledge or furrow all round it. This channel is filled with an insulating oil.

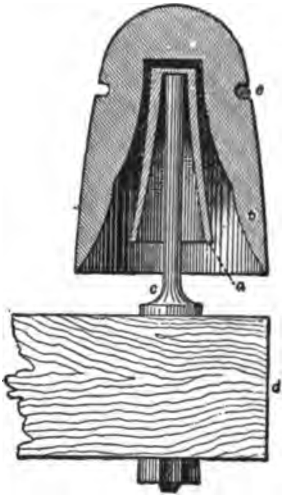


Fig. 349.—Varley's Insulator.

The supports for the insulators are either wooden arms or iron brackets. The arms in England are formed of oak.

No. 16 galvanized iron wire is employed for binding purposes. The form of joint now adopted is that introduced by Mr. Edwin Clark, and known as the Britannia joint. The ends of the wires are carefully scraped clean for about two inches, and laid one over the other; they are then bound firmly together with wire, are smeared with chloride of zinc, and solder is applied in the usual way.

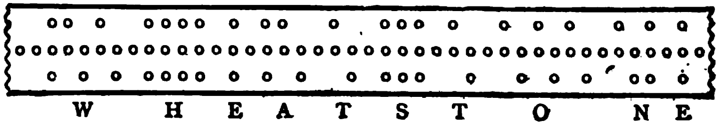
AUTOMATIC TELEGRAPHY.

The object of automatic telegraphy is to give the telegraphic signs more quickly and more correctly than they can be given by the hand. The hand of the operator has a limited speed of working, and both that and the attention or mental strain soon tire. Hence the messages sent by hand soon lose their clearness. Moreover, interruptions and varying conditions of health tend also to render hand-signals illegible. Mechanical means therefore have been devised for assisting the sending clerk, and securing precision. Bain first proposed a plan in 1846 to work with his chemical marking. He punched holes and slits in a ribbon of paper to mark the dots and dashes of the messages, and by drawing the ribbon at a uniform speed beneath conducting brushes over a metal roller, caused contact to be made at corresponding intervals.

The Wheatstone System.—Wheatstone's system of punching has replaced Bain's so far as England is concerned. The punching is done by a special instrument called a *perforator.* It has three keys, one of which is connected with a single punch; a second moves a single punch in a line with the first, together with two other punches, one above and the other below; the third key works two punches in a line with the first, together with a punch above the first, and another punch below the second. Whenever a key is depressed the paper is jerked a step forward. The marks made by the three keys are therefore as follows:—first o, second $\begin{smallmatrix}\circ\\\circ\\\circ\end{smallmatrix}$, third $\begin{smallmatrix}\circ&\\\circ&\circ\\&\circ\end{smallmatrix}$. The first is understood to mark a space, the second a dot, the third a dash. When the punched paper is drawn by clockwork through the transmitter by means of a spur wheel that catches in the central line of holes, the side holes let pins on an oscillating lever make contact alternately with the positive and the negative poles of the battery. The holes for a dot allow a reversal of current at each oscillation;

those for a dash, at each second oscillation. The *receiver* is an ink writer of a sensitive kind, so constructed that to make the disc mark a current has to be sent in one direction and has to be followed by a current in the opposite direction. A dot is written by sending a transient current in one direction to move the disc, another immediately after to bring it back. A dash is written when the reverse current follows the first at a longer interval. But these currents are just what are produced by the contacts through the punched paper in the trasmitter.

The following is a word, as it appears on the punched ribbon:



This automatic apparatus is used in England for ordinary messages on long lines that are much worked, and for the transmission of news on lines to provincial centres. Several clerks can be punching the messages as they arrive, while another is transmitting. The rate at which the latter clerk can despatch the message is more than double that at which he could send with a Morse key. The average rate of working on long circuits with Wheatstone-punched ribbon is about seventy-two words per minute. For short circuits, however, and circuits that are not often charged with a glut of work, it would be a needless expense to fit up this apparatus, for nothing would be gained by delaying the transmission of the message until it is punched, the line and sender being idle meanwhile. The method lends itself admirably to the transmission of news; for one punched ribbon can be used again and again in wiring to different centres the same message.

Alteneck's System.—Fig. 350 represents the system of Hefner Alteneck, which may be conveniently described in this place, as, although it is worked by keys, it combines some of the time-saving qualities of an automatic apparatus. The combination of dots and dashes which form any letter or sign are produced by the depression of a single key. Each key operates by means of levers and wheelwork on a pointer connected with the case D shown in the figure. There are forty-nine keys, here arranged in seven rows; the arrangement being such that the letters, signs, etc., which occur most often are nearest the hand. An enlarged representation of a single element of the case D may be seen in fig. 351. Each key T is connected by means of a lever with a vertical sheet of metal s, which has the letter or sign of the key filed out on its free edge; opposite to these sheets of metal s, nineteen horizontal metal strips Q Q are placed, and behind these a corresponding number of levers H, which are also of sheet metal. The reason for this number will be apparent on examining the length of the longest letter. A dash in the plate S will thrust in three strips, but a dot only one. The longest sign is the nought, which consists of five dashes, separated by four spaces, and therefore requires $3 \times 5 + 4$, or nineteen strips.

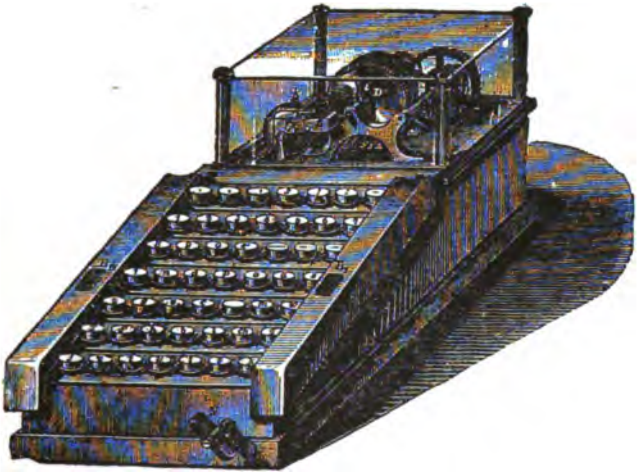


Fig. 350.—Alteneck's Automatic Telegraph.

The levers operate in the following manner to liberate the case D, and to allow it to turn under the influence of its driving weight: The rods *n*, which stand opposite the edge of case D, are fastened to the upper arms of the levers H, and are placed so as to work upon a number of little rods *s s*, which may be pushed a little beyond the surface of the case. The edge *a c* of the case has also teeth which are cut crossways, and in which the trigger *f* catches. When a key, T, is depressed, the strips of metal Q Q, corresponding to the projections on the free edge of the vertical metal plate S, are pushed forward, and affect the corresponding levers H, which in turn transmit the movement to the pins *s*. The

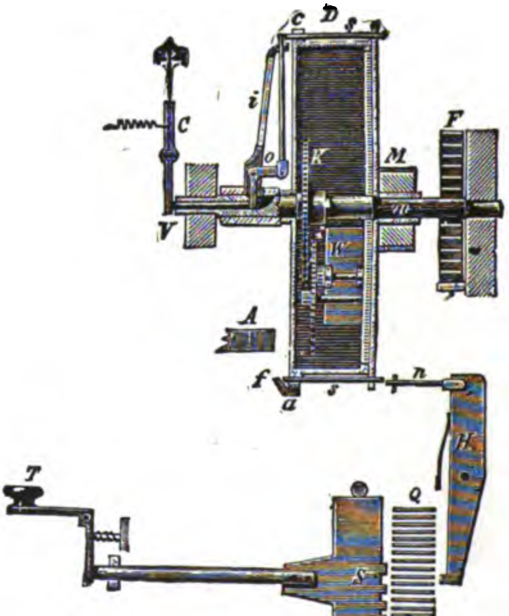


Fig. 351.—Alteneck's Automatic Telegraph.

driving weight, operating by means of the system of wheelwork, tends to turn the case, but the motion is prevented so long as the catch *f* lies between two teeth. When, however, a pin *s* is pushed forward by means of *n*, the catch is removed and the wheel is allowed to turn. In this manner the contour of S is reproduced on the edge of the circumference of D. The letters are transmitted from D by means of the pointer *i*, and the bent lever *o*, which is connected with the lever C. Before the action begins, the contact lever C is forced against the stationary contact by means of a spring, but when the lever O is turned, the pin V is pushed out, and C is forced against the working contact. At the same time the pointer *i*, by passing its end over the projecting pins *s*, brings about the corresponding duration of current, as well as the appearance of the current at the right time. The proper duration of the current can only be obtained when, besides the pushing forward of the pins *s s*, the pointer is also made to move with relative velocity over each group of pins. To bring about this result the case, which rotates in a jerky fashion, is connected with the pointer in the following manner: The shaft of the case is hollow, and through it passes the shaft of the pointer. The case, with its fly-wheel M, bears but lightly on the shaft *m* of the pointer, and at this point one end of a spiral spring, F, is fastened to *m*, while the other end is joined to the frame. When the case rotates, the pointer moves with it, but at the same time the spring is strained, and tends to bring the pointer back to its starting point A. Hence the projecting ends of the rods *s* move across the end of the pointer, and contact lasts for the interval of a dot or dash as the case may be. To make the motion uniform, the toothed wheel K, which is fastened to *m*, drives a small wheelwork which sets the fan W in motion so as to act as a regulator. When the telegram has been transmitted, the pins *s s*, which had been pushed forward, are again brought into their former position by means of an inclined plane not shown in the figure.

DUPLEX AND MULTIPLEX TELEGRAPHY.

By duplex telegraphy is meant the sending of two telegrams in opposite directions at the same time through the same wire. The various methods are all based on the principle of registering alterations in the strength of the current flowing through the line. Such alterations have been obtained by two methods, namely, (1) by using differential relays, or, which is the same thing, by a separation of the two coils of a relay, or (2) by means of a Wheatstone bridge.

The Differential Method.—The system in which the coils of the relay are separated from each other, is shown in fig. 352. The Morse keys *a a* have auxiliary levers *b b*, connected with the relay coils R_1 and R_2, which are independent of each other. The batteries B B are connected with the Morse key; L represents the line which connects the two stations I and II with each other. The batteries of both stations, as may be seen from the figure, are put in series. Let us assume that the key *a* is depressed at station I only, then contact between *b* and *c* is broken, and the current flows from the battery B over *a* and *b* into the coils R_1, thence from the one arm of the relay, and so through the line to

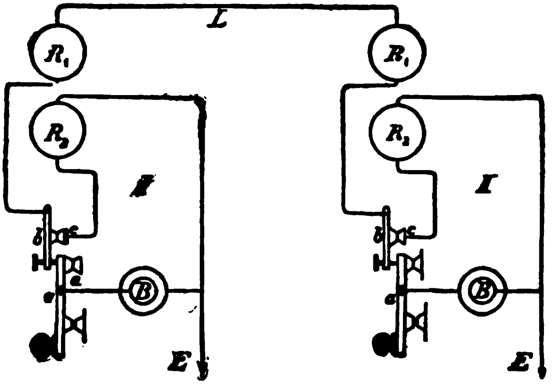


Fig. 352.—Differential Method.

station II. As the spring of the relay lever is very powerful, the current which circulates through one arm only of the electro-magnet is not sufficiently powerful to attract the armature. When the current arrives at station II, and reaches the coils of R_1, it flows over the contact *b c* of the auxiliary lever, and from here through the coils of the second electro-magnet arm R_2, and so to earth E. When the current circulates through both arms of the electro-magnet of station II, the magnet becomes sufficiently powerful to overcome the force of the spring.

When both keys are depressed at the same time the current flows as follows: From the battery B of station I, over *a b* and R_1, through the line L to station II, through the coils of the electro-magnet R_1, and then over *b* and *a*, to battery B of II, and then to earth. The relay of station II will not be affected by the current, because only one arm of the electro-magnet has a current passing through it, unless the batteries B B of both stations have been put in series. By the simultaneous depression of the keys of both stations the coils of the electro-magnet R_1 are connected with the battery of station II, so that the coils have the currents of both batteries flowing through them, and the increased force of attraction of the one magnet R_1 of station II is sufficient to overcome the force of the spring. The same holds good for station I. The result is that the depression of *one* key acts on the distant station, but the simultaneous depression of *both* keys acts on both stations. The arrangement therefore permits of telegrams being sent at the same time in opposite directions through the same wire.

The Bridge Method.—The method devised by Schwendler, in which he uses a Wheatstone bridge, is shown in fig. 353. At the distant stations I and II, B_1 and B_2 indicate equally strong batteries, the zinc poles of which are connected at both stations with earth, whilst the copper poles are connected with the keys T_1 T_2. Above these keys are what may be called the auxiliary levers H_1 and H_2. The contacts 4 of the auxiliary levers are connected by means of the resistances *b* with the earth. From the auxiliary levers lead the branches N_1 L_1, N_2 L_2, N_1 M_1, N_2 M_2. The ends of L_1 and L_2 are connected with each other by means of the line *l*. The ends M_1 and M_2 are connected with earth through the resistances *z*, and L_1 M_1, L_2 M_2 are connected with each other. The resistances *x* and *y* are inserted in the branches, and a *receiving apparatus* is inserted in the connecting line of every two branches. These are represented by the relays R_1 and R_2. Let us consider two cases—first, when only one station is active, and secondly, when both stations are active. When the key T_1 at station I is depressed, the contact between H_1 and 4 is broken, and contact is made between H_1 and 3. From the battery B_1 a current then flows over 3 and H_1 to N_1, and from here partly through the resistance *y* over M_1 and the resistance *z* to earth,

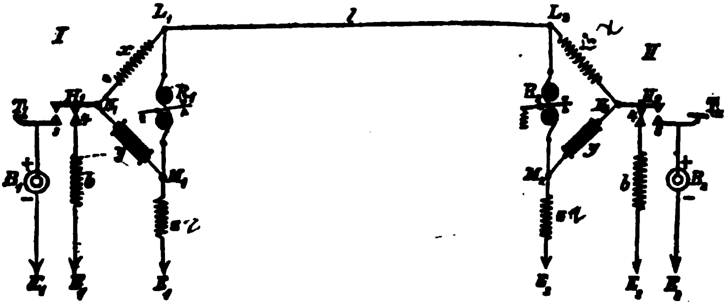


Fig. 353.—Schwendler's Bridge Method.

and partly through the resistance *x* over L_1 into the line *l*. The distance L_1 M_1, which contains the relay of the sending station I, remains without current. When the current arrives in station II at L_2 it divides into two branches, one of which flows over L_2 M_2 through resistance *z* to earth; the other flows through the resistance *x* over H_2 to 4, and then through the resistance *b* to earth. At the receiving station II, therefore, the branch N_2 M_2 forms the bridge, which is without current, and the relay R_2 lies in the branch L_2 M_2, through which a current flows. If, however, both stations work at the same time, the contact between H_2 and 4 will also be broken in station II, and that between 3 and H_2 made. From battery B_2 therefore a current will also flow over T_2, 3,

H_2, x, L_2, and then into the line l. This current being opposite in direction to that sent from station I into line l, and both currents being equally strong, their effects in the line l will be neutralized, *i. e.*, line l will be without current. In each station, therefore, a local current is formed, whose course for station II, for instance, is as follows: The current flows from B_2 over T_2 3 and H_2 to N_2, where it divides in the branches N_2 M_2 and N_2 L_2 M_2; both branches unite again at M_2 and flow over Z to earth E_2. The relay R_2, lying in a branch through which [illegible] current flows, will, therefore, be affected. The method just now described can only be employed successfully when the resistances in the several branches are calculated according to the law of proportion for Wheatstone's bridge.

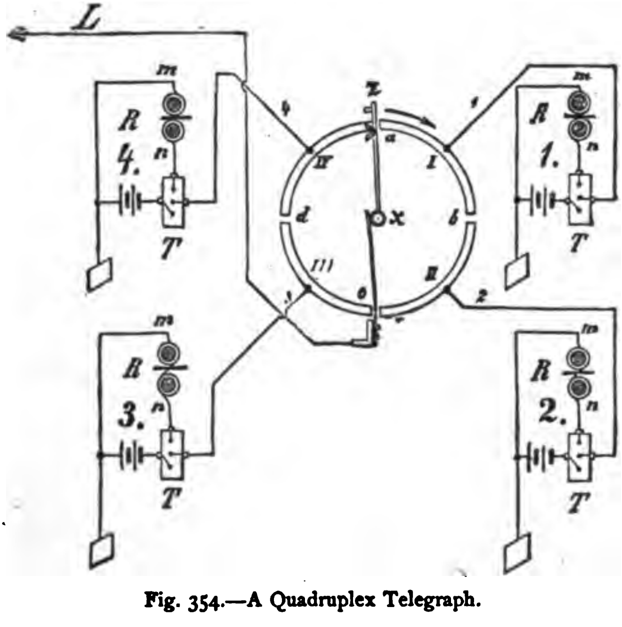


Fig. 354.—A Quadruplex Telegraph.

Multiplex Telegraphy.—The principle of Multiplex Telegraphy is a very simple one, and can be made clear with the help of fig. 354. It represents a station with four Morse systems; R are the writing apparatus, T the keys; each system is connected with one of the sectors I—IV. The line L is connected by means of a sliding spring with the axis *x*, which is made to move by clockwork, and which causes the pointer *x z* to slide over the insulated contact pieces I, II, III and IV in the direction indicated by the arrow. By this arrangement the writing instruments 1 to 4 are connected with the line in turns, and each remains in this position for a quarter of a revolution of the pointer. A second station B, which is connected with A by the line, is fitted in exactly the same manner, and the pointers *x z* at both stations move isochronously, *i. e.*, the pointer of station A moves over sector I when the pointer of station B moves over sector I, and so on. Apparatus 1 of station A will, therefore, be connected with apparatus 1 of station B by means of the line, as long as the pointers *x z* move over the contact piece I. The apparatus 1 can therefore send and receive signs. When the pointers of both stations have reached sector II the apparatus 2 of the two stations will be connected, and this will continue until all the apparatus have been connected, that is, until the pointers have made one complete revolution.

This explanation is probably sufficient to make the principle understood, but to show the details of the connections we must examine a complete system in which the above principle is applied; for this purpose we will select the multiplex apparatus by Bernhard Meyer.

Meyer's Multiplex Telegraph.—Each of the four attendants has to use his quadrant, so as to give all the necessary signs during the time allotted; but to send the call-signal involves a task which would be beyond the powers of any one key without a a special contrivance. In order to make this possible several keys are connected with each other, so that by depressing one key, two or three more are depressed at the same time in a manner to be described later on.

Each quadrant, fig. 355, is sub-divided into twelve parts (1 to

12, ; the parts 1 to 11 are connected with the axes of the eight keys I^1 to IV^1 and I^2 to IV^2. The rest of the contacts of the keys I^2 to IV^2 are connected with the portions 3, 6, 9 and 12, and the remaining contacts of keys I′ to IV′ are connected by means of the branches e_2 e_5 e_8 and e_{11} with the portions having the same numbers. When the key I′ is depressed, and the pointer $x\ z$ makes contact with the portion 1, a current will flow from the battery B over i, the key I′ at $b\ o$ to 11, and through the pointer $x\ z$ into the line. When all the upper four keys I′ to IV′ are depressed at the same time, a current will first flow through the portion 1 into the line at the moment when the pointer $x\ z$ glides over 1. A second current follows as soon as the pointer has reached the portion 4; a third and a fourth current reaches the line when the pointer has reached the portions 7 and 10. By depressing four keys at one and the same time, four different current impulses can be produced, which, therefore, may be used for producing four separate Morse signs at the receiving station. The nature of these signs (points or dashes) depends upon the duration of the several currents, and their duration depends upon the velocity with which the pointer moves and the length of the contact pieces 1, 4, 7 and 10. If the pointer moves with uniform velocity and the different contact pieces are of equal length, the four currents will be of equal duration, and four equal signs will be produced. The four signs obtained by depressing the keys I′ to IV′ are points. These keys are, therefore, called point-keys, and the contact pieces 1, 4, 7 and 10 are called point contact pieces.

It will only be possible to send a current like the one described when the pointer has passed the second, third and fourth quadrant, and has again reached the first contact piece of quadrant I.

Suppose we depress the lower row of keys I^2 to IV^2; currents will flow from the battery through the different keys, and through the contact pieces 2, 5, 8 and 11, when the pointer touches the latter. The direction of current for key I^2, for instance, is as follows: From B over $i\ i$ . . through key I^2, from b over o

through *2 2* to the contact piece *2*, then through the pointer *x z* into the line. The circuit of key I^a, however, branches off at e_2, and allows the battery current to flow with the line as long as the pointer *x z* does not make contact with piece *2* by the depression of I^a, but remains upon contact piece 1. The current now flows from e_2 over *b* of key I′ and o into contact piece 1. The same phenomena occur when keys II^a, III^a and IV^a are depressed. If the receiving apparatus is, as before, an ordinary Morse writer, four signs are produced. These signs will be dashes, because the current is not only maintained during the time the pointer glides over one contact, but also when two contacts are passed, on account of the branch at *e*. The first current lasts till contact pieces 1 and 2 are passed, the second current till 4 and 5 are passed, the third till 7 and 8 are passed, and the fourth till 10 and 11 are passed. The signs produced by depressing the upper keys and lower keys will be of the following nature:

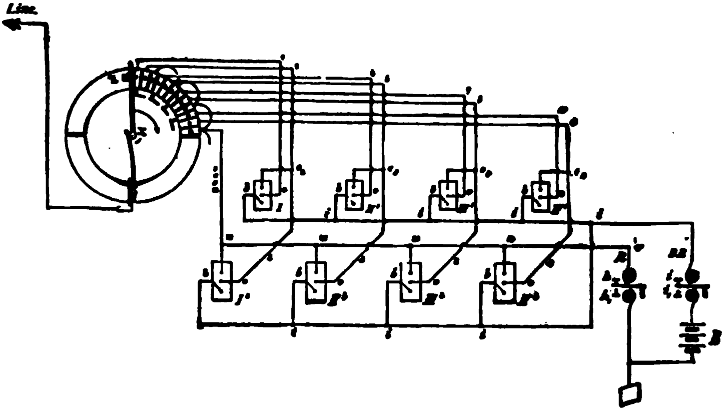


Fig. 355.—Meyer's Multiple Telegraph.

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The contact pieces 2, 5, 8 and 11 are called "complementary" contact pieces, and the keys belonging to these are called "dark keys." These Morse signs are marked on the first quadrant of fig. 355, as they can be produced by means of the twelve contact pieces.

In Meyer's system not only is the length of the signs of importance, but also their position: this greatly simplifies matters, because each written character needs at the most only four Morse signs. In the ordinary Morse writing, a point, for instance, signifies the letter *e*. In Meyer's Morse system, however, a point signifies in the first place the letter *e*, and in the second place a full stop, or thirdly a (punctuation) dash. Meyer's system not only saves room on the contact disc, but also saves time on the line. Each quadrant corresponds to a branch station, at each of which one attendant must be placed; four attendants will therefore produce four characters in one unit of time. The unit of time (that is, one complete revolution of the pointer) is taken as half a second; we have, therefore, $60 \times 2 \times 4 = 480$ characters per minute.

We shall next trace the direction of the currents to the receiving station, and, as sending and receiving stations make use of the same apparatus, we may also use fig. 355 for this purpose. Let us first assume that the current arrives at the receiving station just at the moment when the contact brush z of the pointer $x\ z$ is in contact with the first quadrant of contact piece 1; the printers of both stations move synchronously, and therefore it follows that this current can only have been sent through the contact piece 1 of the first quadrant at the sending station. This current flows into the receiving station over $x\ z$ and the contact piece 1 to key 1^1, then to e_2, over 2 to key 1^2, and then to $u\ v$, flowing to earth through the relay R, which it will therefore bring into action. Again, let us assume that the current is sent at the moment when the points of both stations make contact with the contact piece 2. The current arrives through the line, flows over $x\ z$ to the contact piece 2, through 2, e_2, 0 to key 1^2, through $u\ v$ to the relay R, to earth. A current reaching the station through the contact piece 3 would flow over 3, 6, 9 and 12, over $u\ v$

through the relay R, and then to earth. The currents for the point contact pieces 4, 7 and 10 would exactly correspond to those of the contact piece 1, of contact piece 2, of complementary contact pieces 5, 8 and 11; and to those of contact piece 3, and the separating pieces 6, 9 and 12. Each current then arrives at the station and flows to earth through the relay.

The same holds good for the twelve contact pieces of the second, third and fourth quadrants. The receiving relay will, therefore, be affected by each current, irrespective of which contact piece or quadrant the pointer happens to be on. For every revolution of the pointer four characters would be produced in the following order: First character of the telegram sent from 1, first character of the telegram sent from 2, and so on. Then second character of telegram from 1, second character of telegram from 2, etc., etc. After mixing the four telegrams in this manner it would be difficult to rearrange them again. It is, therefore, necessary that the separate telegrams should be received separately at the station which is affected. This is done by using four writing instruments at the receiving stations. The connection of these, and also the natural arrangement of the eight keys of one quadrant, are shown in fig. 356. The disc is further furnished with two concentric contact rings *n* and *m*, of which the inner consists of one piece, whilst the middle one is divided into four portions m_1 m_2 m_3 m_4. The fork-shaped brush *g* g_1 is fastened upon the pointer, and one prong of this brush slides over the quadrant *m*, and the other over the undivided ring *n*. One pole of the local battery *b* is connected with the latter, the second pole is connected with the armature lever of the relay R; a wire leads from the contact screw h_1 of this relay to the writing apparatus S_1, which is connected on the other side with the quadrant m_1 of the middle ring. Owing to this connection the action of the apparatus is as follows: The current reaches pointer *x z*, and flows from there over the contact piece 1, then through the key-work *b u* and over *v m n*, through the relay R, to earth. The relay is affected and closes the local circuit for the writing apparatus S_1 by pressing its lever on h_1. The local current passes from b over h_1 into the writing apparatus s_1, and then into the quadrant m, upon which the brush g of the pointer has to be arranged, because the lines of separation of the quadrants of both rings fall in the same radii. From g the current reaches g_1, then the ring n, and so flows back again to the battery b. By connecting all four quadrants m_1 m_2 m_3 and m_4 with the writing apparatus s_1 s_2 s_3 and s_4, as shown in fig. 357, four telegrams are received by the writing apparatus, which are separate from each other.

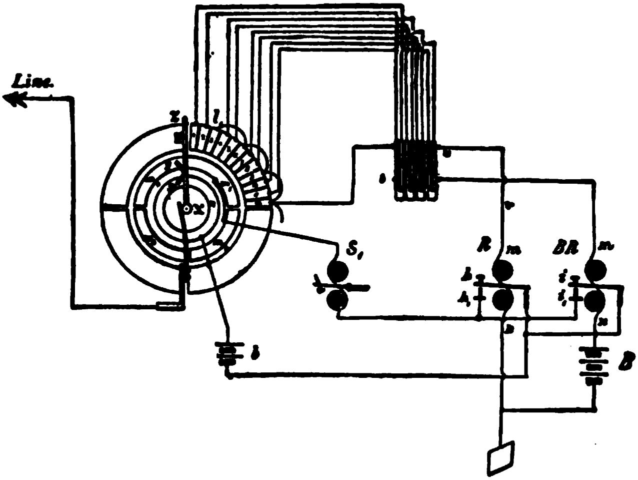


Fig. 356.—Meyer's Connection of Receiving Instruments.

Meyer's Printing Apparatus.—As all multiplex and distinct systems require a special arrangement for the printing apparatus, we shall give an explanation of Meyer's. In the first place, the currents of all four quadrants may only affect one writing apparatus, so that all four telegrams are printed by it. Meyer uses for this purpose a thread, *a* K K *e*, as shown in fig. 358, which surrounds the cylinder Z Z. The paper strip *p p* is carried by the rod S S, which is in connection with the armature of a magnet. Every time this armature is attracted by the magnet the paper is pressed against the thread upon the cylinder z z; the latter has its axis connected with the apparatus in such a manner that its velocity and that of the pointer upon the contact disc are synchronous. A roller *t*, fig. 359, furnishes the thread with ink. When now *p p* is pressed against the cylinder, that portion of the thread will produce a sign on the paper which happens to be opposite to it, as, in fig. 358, the place *d*. If the contact be for a long period, the line *d g* will be produced; if the paper remains pressed against the cylinder during a full revolution of

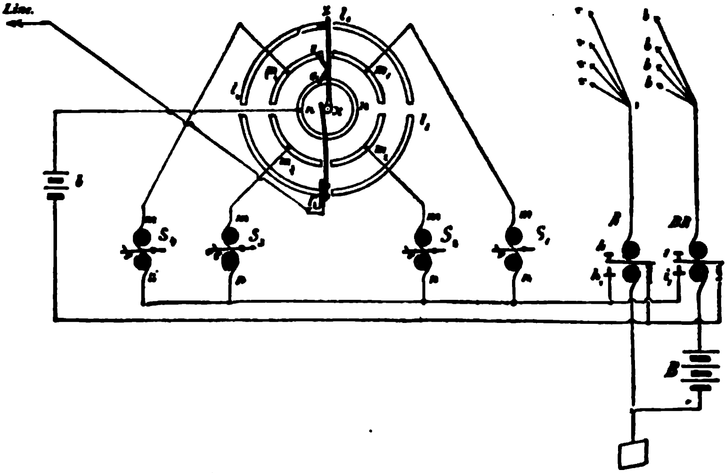


Fig. 357.—Diagram illustrating Meyer's Multiple Telegraph.

the cylinder, the line *f* f_1 will be produced. As a complete revolution of the cylinder corresponds with a complete revolution of the pointer on the contact disc, a quarter of a revolution of the cylinder will correspond with the passage of the pointer over one quadrant. The piece I of the thread will, therefore, correspond with the first quadrant, piece II of thread with second quadrant, piece III with quadrant III, and piece IV with quadrant IV. As the cylinder and pointer move synchronously, the following must also take place: The several portions of the thread *a b* must successively be nearest the paper as the pointer glides over the contact pieces of the first quadrant, and, moreover, the pieces II, III and IV of the thread must correspond to the second, third and fourth quadrants respectively. The mode of action of the apparatus will, therefore, be as follows: When the pointer has gone over the twelve contact pieces of the first quadrant,

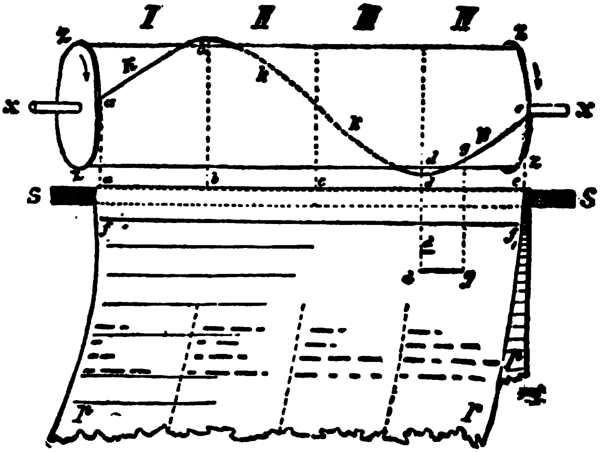


Fig. 358.—Meyer's Printer.

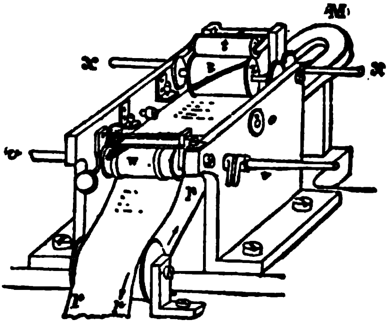


Fig. 359.—Meyer's Printer.

corresponding currents have reached the writing apparatus, and at the same time the cylinder has completed the greater revolution, and has brought the several portions of *a b* in contact with the paper *p p*. During this time the magnet has, by means of its armature, raised the rod S S as often and sustained it as long as corresponded with the arriving currents. The paper will, therefore, have in the first quarter of its breadth all those Morse signs which were to be applied from the sending station, *i. e.*, the first character of the telegram sent from the station will be reproduced at the receiving station. The pointer now moves over the second quadrant of the contact disc, and upon the second quarter of the paper appear the first characters of the telegram sent from station II, and so on, until the pointer again reaches the contact piece I of the quadrant I. Meanwhile, the paper has advanced some millimetres, and is ready to receive the second characters of the four stations. Hence, we have in the first quarter of the paper the telegram from the first station, at the second quarter the telegram from the second station, etc.

Fig. 359 represents the single printing apparatus of a branch station. M represents a powerful permanent magnet, the armature of which is an iron core, having wire coiled round it. The latter is fastened to a frame that moves about O, one side of which consists of the rod S S, which carries the strip of paper. When the coils are without current the permanent magnet attracts the iron core, and turns the frame in such a manner that the paper is pressed against the thread R of the cylinder Z. When a current passes through the coils it affects the magnet, so that like poles are opposite each other in the permanent and electro-magnets. These poles repel each other, and the frame O is again turned, and the paper removed from the cylinder.

Fig. 360 shows an arrangement of the four printers as four separate instruments. X X is the axis of the printing cylinders, and *v v* the axis of the rollers W, which move the strips of paper in the direction indicated by the arrows. S_1—S_4 represent the four printing apparatuses; each sending apparatus consists of four black and four white keys, and has an alarm arrangement

u_1—u_4, which indicates to the attendant when the pointer has reached the quadrant which is under his care. All the branch instruments are worked by means of wheelwork, which is placed at instrument 1, and moved by a heavy weight.

CABLE TELEGRAPHY.

Long over-ground lines offer difficulties caused by the electric charges which the wires receive, but these difficulties are still further increased in cable telegraphy. The cable, consisting of copper and iron wires, separated by insulating substances, will behave like a Leyden jar. If the copper wire forming the inner coating receives positive electricity, a corresponding quantity of negative electricity will be held bound by the outer armature surface in contact with the water, and answering to the outer coating. The charging and discharging of the cable, therefore, not only require considerable time, but may also cause indistinctness of signs.

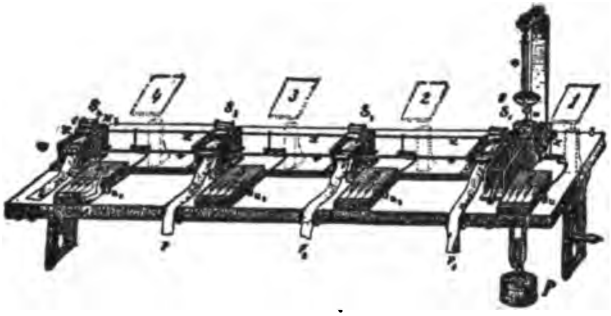


Fig. 360.—Meyer's Multiple Printing Apparatus.

Special Apparatus for Cable Telegraphy.—If currents of high potential are used, not only are these disadvantages increased, but the insulation becomes much less perfect. Specially-constructed apparatus have, therefore, to be used with cables like the transatlantic. As only very weak currents could be utilized, care had to be taken that the receiving apparatus should possess great sensibility. For this purpose mirror galvanometers have been used.

Mirror Galvanometers.—It is clear that signs may be produced by the deflections of the needle just as with Morse's dash and point. Formerly, therefore, mirror galvanometers were exclusively used for cable telegraphy. A form which is frequently employed is represented in fig. 361 (Thomson's). The cylindrical bobbin A consists of two coils, which are separated from each other, and each of which has a resistance of 1,000 ohms, so that resistances of 500, 1,000, and 2,000 can be obtained by joining both coils parallel, or by using one coil only, or by joining both coils in series. The copper tube R, which is closed at *a*, but open at the other end *b*, is inserted in the hollow space of the coils, and carries a magnet *n s*, with the mirror at *b*. The mirror is suspended by means of the cocoon threads c_1 c_2. The bent magnet N S serves to neutralize the attraction of the earth. As it would be rather fatiguing to observe the deflections of the needle through a telescope, a beam of light or picture of a slit in a lamp screen is thrown upon a scale, for which Siemens and Halske have constructed the apparatus shown in fig. 362. The rays of an oil lamp are allowed to pass through a small slit m_1 m_2

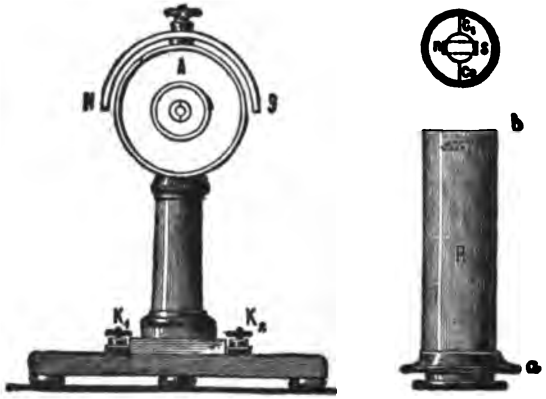


Fig. 361.—Signal Galvanometer.

and are then collected by the lens L. The slit can be adjusted by means of the screw X. The scale *t t* is fastened at the upper edge of the case, and can be moved along by means of the screw S and a toothed bar. The mode of action of this apparatus in connection with the galvanometer is shown in fig. 363. The rays of light coming through the slit $m\ m_1$ are thrown by the lens upon the mirror *s* of the galvanometer, which reflects the rays at *a* upon the scale *t*. The image thus produced falls upon zero on the scale when the coils of the galvanometer are without

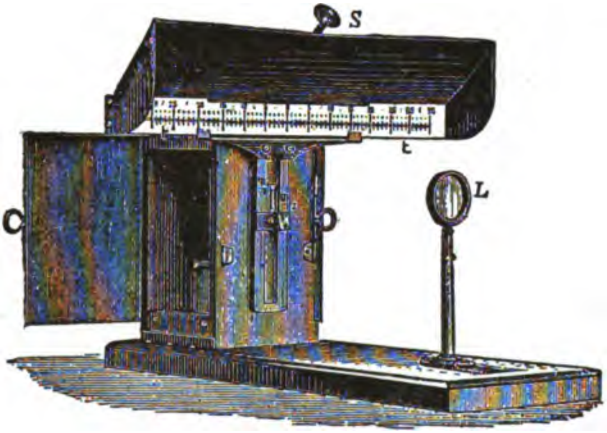


Fig. 362.—Scale for Galvanometer.

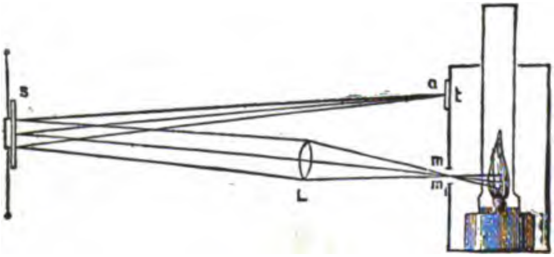


Fig. 363.—Action of the Galvanometer.

current, and the image moves to the left or right, according as the needle is deflected to one side or the other. To produce this deviation of the needle, even with the longest cable, a battery consisting of from 5 to 10 copper-zinc elements is sufficient.

In order to send currents of either direction into a cable, a double tapper (I II, fig. 364) is used, which consists of two brass springs, I and II, fixed at one end, and having the finger-buttons at the other. The wires from the battery are brought to two strips of brass, one of which (1), connected with the zinc, lies below the springs, but without touching them; the other (2), connected with the copper, passes over the springs, and is in contact with both when they are not pressed down. Whichever spring is pressed down takes the current from the zinc. (See fig. 321.)

The first experiments made with transatlantic cables showed that a new difficulty is encountered when stations that are far distant are connected to earth, that is to say, when the ends of the cable are connected to earth in the usual way, so as to exclude connection of every battery. The experiments showed that there is often a considerable difference of potential between distant parts of the earth, which causes earth currents to flow along the cable or leads connecting them. Varley avoided this evil by inserting condensers, to which the cable-ends were connected, and thus avoiding the direct connection of the cable with earth.

The connection of the apparatus at the cable stations, and the joining of the stations, is shown in fig. 364. From the galvanometers *g g′* of stations A and B, leads *n n′* go to earth E_1 E'_1 and to the commutators *u u′*, which, when at rest, have the position shown at *u′*. Wires lead from the commutators to the condensers M M′, the second coats of the condensers being joined to the cable. The necessary currents are furnished by the batteries *b* and *b′*, the zinc poles *z z′* of which are joined to the keys I II by means of 1 1′, the copper poles *c c′* to keys I′ II′ by means of 2 2′. The keys I I′ are connected with the commutator, and keys II II′ with earth E_2 E_2'.

When A wishes to communicate with B, the commutator is moved from its position as in *u′*, and assumes that shown in *u*. The negative pole *z* of the battery is then connected with the commutator *u* by depressing the key I, and the positive pole *c* of the battery is connected to earth E$_2$ by depressing key II. In the former case negative electricity will flow over I, and the commutator *u* to the condenser M, where it spreads over the lower plate, and induces positive electricity in the upper plate, while it sends a certain quantity of negative electricity into the cable. The negative electricity flows through the cable and reaches the upper plate of the condenser M′, while it binds positive electricity in the lower plate, and allows negative electricity to flow through *u* and the galvanometer to earth E′. The needle is deflected, and the light image moves in a certain direction from the zero point on the scale. A negative current is now being sent through the galvanometer *g′* of station B by depressing key I at station A. But when the key is lifted again a positive current is sent through *g′*. The first current causes the needle to deflect, while the second one brings it back again to its former position. Not more than fifteen to seventeen words per minute can be obtained when galvanometers of the kind above described are used, but other instruments have recently been constructed, such as the siphon apparatus, by Sir William Thomson; the undulator, by Lauritzen; and the soot writer, by Siemens, which permit of a greater speed of signalling.

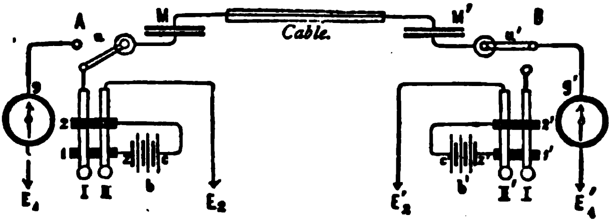


Fig. 364.—Cable Connections.

The Siphon Recorder.—Fig. 365 represents an ingenious and interesting instrument called the siphon recorder, invented by

Sir William Thomson. The arms of a powerful magnet, consisting of a number of steel plates, *Sch*, are furnished with the

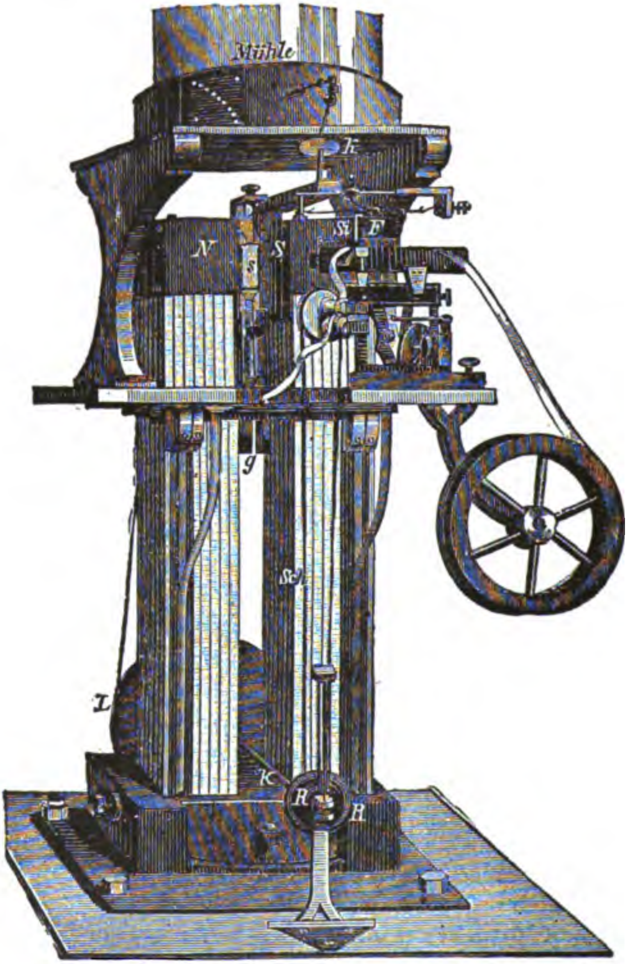


Fig. 365.—Thomson's Siphon Recorder.

shoes N and S: the wire coils *r r* are suspended between these, and joined to the leads at *x* and *y* (fig. 366). To make the magnetic field, in which this frame is suspended, more powerful, a piece of soft iron S N is placed inside the frame. The coils are fastened to the cocoon thread *a*, and the cocoon threads *b b* serve to maintain them in a certain position by means of the little weights *g* (fig. 365). When a current flows through the coils the frame will be turned in one or other direction, according to the direction of the current. This motion will be transmitted by means of the cocoon threads and a lever to the writing arrangement, which consists of the glass siphon S *i*, whose upper arm dips into the ink vessel F; while its other arm, which terminates in a point, marks the strip of paper that is slowly moved past it. A straight line is produced on the paper while the siphon is at rest, but when it is influenced by the electric current, by means of the wire frame, zigzag lines are traced on the paper, which correspond to the direction of the currents which have been sent through. An alphabet has been constructed of these lines, as shown in fig. 367; before *a* and after *z* are signs which signify "All right," "Understood."

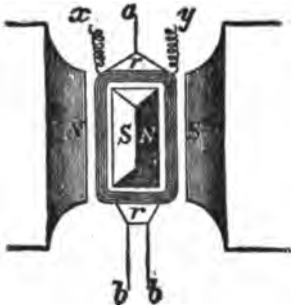


Fig. 366.

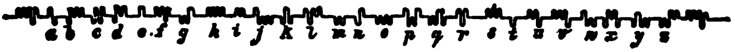


Fig. 367.—Siphon Writing.

In order to produce distinct marks on the paper, the point of the siphon is made so fine that the ink does not flow from it by capillary attraction alone, but has to be electrified before it can be used; this is managed by means of a so-called mill, which consists of an electro-magnetic motor of the simplest construction, combined with an induction machine. Upon the gutta-percha disc of the latter are metal spokes arranged radially, which have pieces of iron attached to their ends; underneath this wheel is an electro-magnet, the coils of which have intermittent currents passing through them, which causes the attraction of the succeeding iron pieces, and by this means the wheel is made to rotate. The wheel is surrounded by two semi-cylindrical metal jackets, one of which is electrified in the beginning. When the apparatus is set in motion, induced electricity is generated. The negative pole of this induction machine, as well as the shaft upon which the paper rests, is connected with earth. Electricity enters the ink vessel from the positive pole by means of plate K, and from there reaches the siphon. The fluid in the siphon is, therefore, always positively electrified, while the shaft under the strip of paper is negatively electrified. A continuous current of sparks passes from the siphon point to the paper roller, and takes the ink particles along with it, and deposits them on the paper. The electro-motor also serves to set the wheelwork, which is connected with the strip of paper, in motion.

The connection of two stations having siphon recorders is shown in fig. 368. The batteries B B′, of stations I and II, are connected with double keys, from which the leads run over the commutators U U′ to the recorders. The contacts upon the ebonite pieces *m* *m′* of the commutators are connected with screws T_3. The contacts 1, 2 and 3 of the ebonite pieces *n* *n′* are connected with the keys and with the earth. The letters s_1 and s_2 indicate the wire frames, and C_1 and C_2 the condensers. When I wishes to communicate with II the commutator of station I is placed upon contact 3 at *n*. By depressing the lower key at station I, a positive current from battery B will take the following way: Through the lower key into the contact 3, and from *n* to U. Here it divides into two branches; one branch flows from *m* to T_3, the other to T_1, where it again divides into two branches, one of which flows through the frame s_1, while the other flows over the varying resistance T_1 T_2 to the condenser C_1. As the resistance of these two branch currents is considerably greater than the resistance which the branch current encounters at T$_3$, a current flows through S, which is only just strong enough for recording the telegram to be sent, while the main current flows to the condenser. Between C$_1$ and C$_2$ the same phenomena happen as were considered in connection with fig. 364. A positive current arrives at station II and flows through the frame s_2 over T$_1$ U$'$ and the contact 1 of m' into the double keys, and thus to earth at E$'$, that is to say, a positive current flowing through the frame s_2

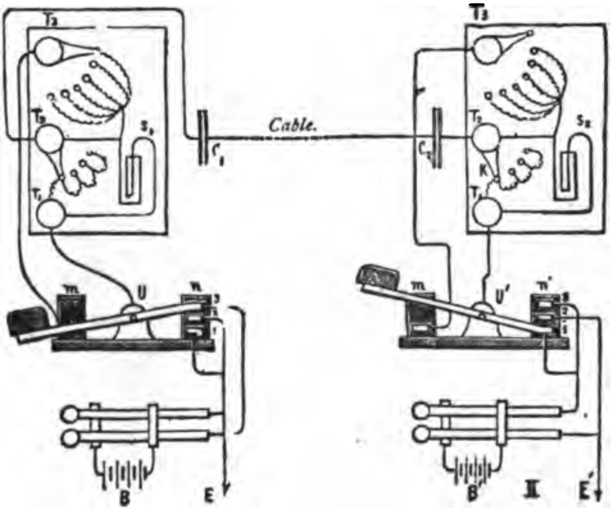


Fig. 368—Connection of Two Cable Stations.

deflects the frame in a certain direction, and traces a certain curve on the paper by means of the siphon. When the upper key of station I is depressed, the positive pole of battery B is connected with earth at E, and a current is enabled to flow from the negative pole, over contact 3 to n, and so on to the condenser C$_1$. A negative current will flow from the condenser C$_2$ through the frame s_2, and will then be deflected in a direction opposite to its former direction, and thus cause the siphon to trace a curve in the opposite direction also.

HOUSE AND HOTEL TELEGRAPHY.

The apparatus used for telegraphy in houses and hotels is of a very simple construction, and usually consists of a key for making contact at the place from which the communication is sent, with a bell and indicator showing either the purpose of the communication or the number of the room from which it is sent. The keys used have frequently the form shown in fig. 369 in plan and elevation, and consisting of a base A, a cover B, and a plug C. The ground disc A is furnished with the contact springs ff', which are fastened by means of screws at *a* and *b*, and overlap, but do not touch at their other ends unless the plug *c* be pushed in. The case B in which the plug *c* is first inserted is screwed upon A, which is furnished with the knob *c*. The springs ff' are made of steel or German silver, and are connected with the

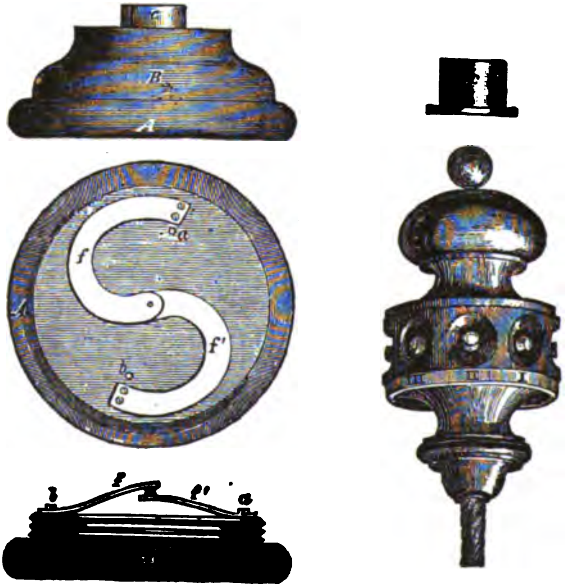


Fig. 369.—Keys.

leads at *a* and *b*. By pushing in the plug the springs $f f^1$, which are connected in the same circuit with the battery and the bell, are pressed together, and the circuit is closed. The drawing to the right represents a suspended key with the knobs I, II, III.

When the installation is worked with constant currents, only one spring *f* is fastened to the ground plate *a*, and when at rest it leans against a support fastened at *f*, which is in connection with one wire of the leads, whilst the other wire is connected with the spring. By depressing the knob *c*, the spring is pushed in, and contact with the support ceases, so that the current is broken. The so-called vibrators or tremblers are used for receivers. These consist of bells such as those shown in fig. 348. The connection of the bell with the key is very simple when it is only required to give a certain signal from a certain place, and when no return message is necessary. One pole of the battery is connected with one spring of the key, while the line-wire connects the second spring of the key with the bell, the second clamp of the bell being connected with the second pole of the battery. Where signals are to be sent and received, the connection would be as shown in fig. 370. T T represent the keys, and G G the bells, which are inserted in the circuit of battery L B. A connection for an intermittent current is shown in fig. 371.

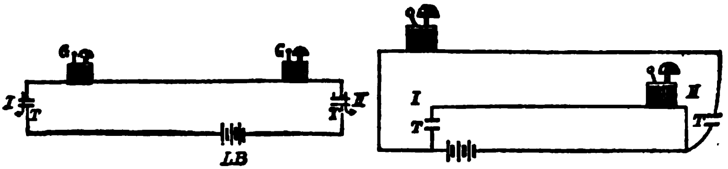


Fig. 370. Fig. 371.

Connection of Vibrators.

Different contrivances are connected with the bells in order to show from which room the message has been sent. Fig. 372 represents Bréguet's indicator. The armature A is fastened above the electro-magnet M, by means of the spring *f*. The catch S consists of sheet-metal; it is movable about *o*, and with its hook *n* hooks on to the end of the armature; it is maintained in its

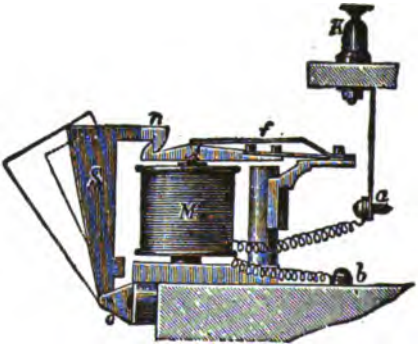


Fig. 372.—Bréguet's Indicator.

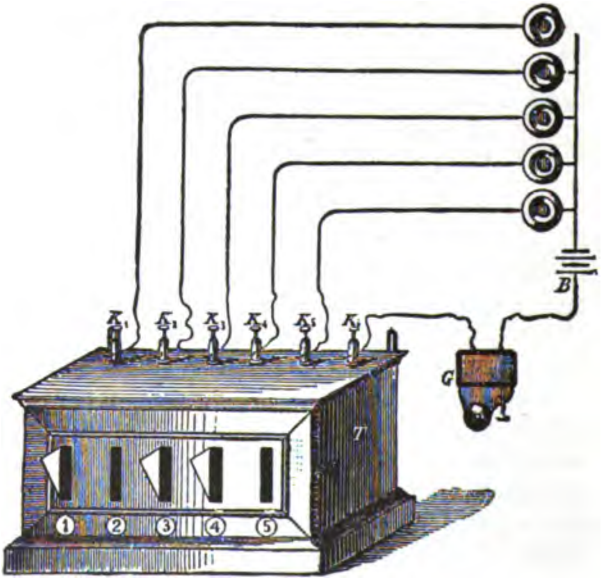


Fig. 373—Bréguet's Box of Indicators.

vertical position as long as the magnet is without current, but as soon as a current passes through the coils of the electro-magnet, the armature moves downward, and S assumes the position indicated by the dotted lines. The indicator box T, fig. 373, has as many of such pieces of apparatus as there are keys connected with the battery B and bell G. The ends *a* of the electro-magnets are connected with the keys by means of the clamps K_1—K_5. The other ends of the wires of the electro-magnets lead to clamp K_6, from which a wire leads to the bell G, the second wire of which is connected with one pole of the battery. The second pole of the battery is connected with the second contacts of the keys. If, for instance, the third key is depressed, the bell rings, and at the same time the indicator makes its appearance; the indicator is pushed into its former position again by the attendant.

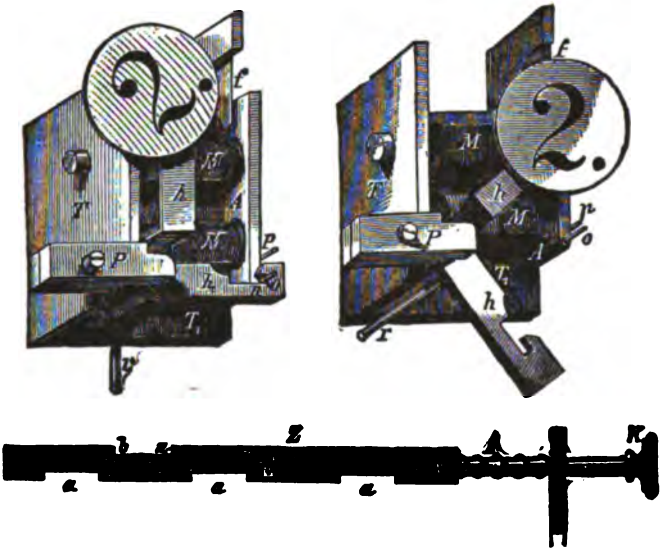


Fig. 374.—House Indicators.

An indicator having numbers, constructed by Hagendorff, is shown in fig. 374. The electro-magnet M M is screwed to the wall T of the frame, and its armature A is held back by means of a spring *f*; the bent lever *h* h_1 is pivoted to the piece P, and its arm *h* carries the disc with a figure; the disc, when at rest, stands vertical, and is maintained in its position by the pin *o* of the armature, which catches the lever-arm h_1 at *n*. When a current passes through the coils of the electro-magnet, its armature is attracted, and the pin *o* allows the lever to drop down. The lever then assumes such a position that the disc makes its appearance before a little opening in the indicator box. The lever is made to assume its former position again by means of the rod Z, the knob K of which is placed outside the right wall of the box; by pulling this knob the rod Z moves from left to right, and catches the rods *r*, which are fastened to the lever, with its openings *a a a*. The pin *s*, which is visible in the open portion of the rod Z, serves to prevent the rod Z from being pulled out too far, and in this task it is further aided by the spring *f*. When not only signs, but whole messages are to be sent, the simplest plan would be to have a double telephone station fitted up; needle and dial instruments, however, are frqeuently used for this purpose.

Automatic Alarm Apparatus are frequently used to indicate or sound an alarm under certain circumstances of danger, as when, for instance, a door, window, etc., is opened by strangers, or when the temperature has risen or fallen beyond a certain point, etc., etc.

Door Contacts.—The opening of a door can be indicated by means of so-called door contacts, which are inserted in the circuit of a battery. Two of such contacts are shown in fig. 375. The metal plate A A is let into the jamb, so that its surface A A is in the same plane as the surface of the jamb. Inside the plate, which is connected with the leads at *a*, is fastened the contact *c*, which touches a contact *f* when the door is opened; the spring *f* is fastened at the top of plate A A, and from it the second wire leads. As long as the door remains closed it presses the insulated knob K against the spring *f*, so that contact is broken at *c*. When the door is opened *f* pushes the knob K out, and makes contact with *c*. The current flows over *a*, A A, *f*, *c* and *b*, and the bell rings until the door is shut again. When the opening of a door has to be indicated by a short signal, only the contact to the right in fig. 375 is used. To the metal piece *c d* is fastened the spring *b*, with its horn piece K. The spring *a* is fastened parallel to spring *b*, and each of these springs is connected with one wire of the leads. The arrangement is fitted to the jamb in such a manner that the door-edge, when opening or shutting, passes over the spur-piece K. A bell connected with this contact will ring as long as spring *b* is in contact with *a*.

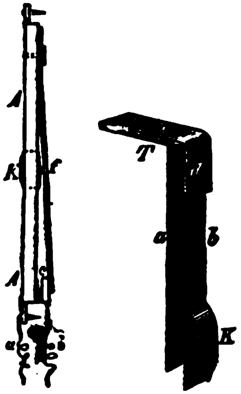


Fig. 375.—Door Contacts.

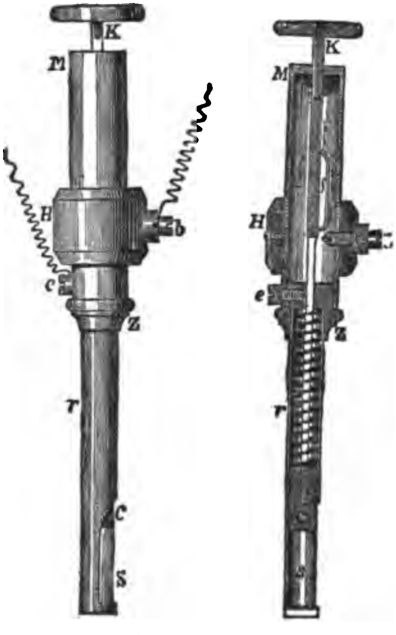


Fig. 376.—Fein's Fire Alarm.

Fire Alarms.—An automatic fire alarm, which has been constructed by W. F. Fein, the action of which depends upon the fusibility of some alloy, is shown in fig. 376. The brass tube M has an ebonite ring attached to it at H, through which the contact screw *b* passes, being insulated thus from M; the tube *r* is fastened to the middle piece Z, and a rod passes through both

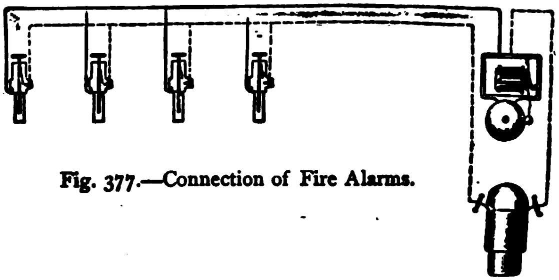


Fig. 377.—Connection of Fire Alarms.

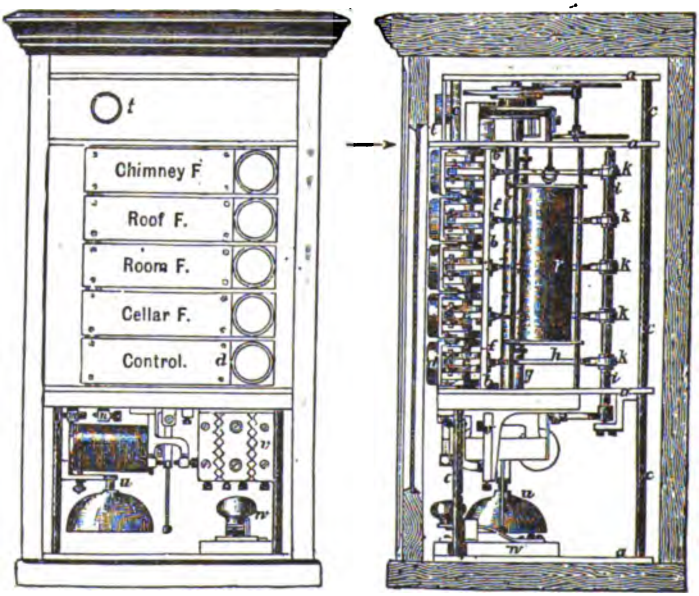


Fig. 378.—Egger's Fire Alarms.

tubes and terminates in a knob K, which presses upon a cylinder S, consisting of the fusible alloy. The apparatus is now inserted in the circuit of a battery; when the cylinder S melts, the rod slides down the tube *r*, and makes contact with the screw *b* and the portions of the apparatus in connection with the spring *f*. Several of these instruments may be inserted in a circuit, as shown in fig. 377.

Fig. 378 represents an apparatus constructed by B. Egger, of Vienna, by means of which any person may communicate with the central station of a fire brigade. The instrument has five keys: the highest has the words "chimney fire," the next "roof fire," then "room fire," "cellar fire," and "control." At the bottom of the apparatus are placed the bell *u*, a Morse key *w*, and the lightning plate *v*. From the figure to the right we see that the whole apparatus is divided into three portions by means of the four plates *a*, which are supported by *c c* and *b b*. The uppermost portion has a wheelwork, and the middle portion is fitted with the five keys. The arrangement of one of these is shown in detail in fig. 379. The key *d* which moves about *f* is pressed against the front wall of the box by means of the spring *p*. The key is connected with the arm *e* by means of a joint; the end of this arm rests upon the sector *h*, which moves about *g*. The lever K which moves about *i* stands opposite this sector in such a position that the angular piece *l* touches the periphery. The spring *o* has a platinum contact, which, when it is at rest,

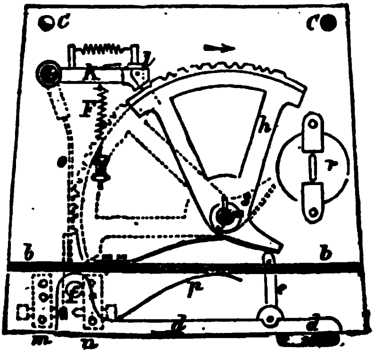


Fig. 379.—Key of the Alarm.

touches the contact screw *m*, and is maintained in this position by means of K and the spring F. The weight *r*, which moves between guiding bars, sets the wheelwork in motion. When the key *d* is pushed in, the sector *h* assumes the position shown by the dotted lines and lifts the weight *r*. If the key is allowed to assume its former position, the lever *e* also goes back into its former position, and the sector *h*, influenced by the descending weight *r*, likewise moves back into its former position. During this motion of the sector the angle *l* has to follow the inequalities of the periphery of the sector, and this causes the lever K and the spring *o* to vibrate, and to make contact alternately at *m* and *n*. By referring to fig. 380 it will be seen that the contact *n* is connected with the lever *o* as well as the lever *k*, and therefore it follows that every time *o* touches *n* a current is sent off. These different currents produce the word which is on the key at the receiving station. At the receiving station are arranged a lightning plate B (fig. 380), a relay R, a galvanometer G, an alarm W, a Morse apparatus M, a key T, the line battery L B, and the local battery O B. When the key W is depressed a current flows from the line battery L B over T, through the galvanometer G, and the relay R, to the plate B, thence through the line to the automatic apparatus, and then through the lightning

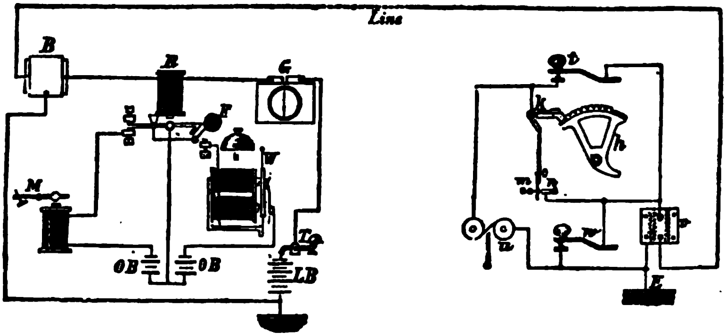


Fig. 380—Connection of Automatic Fire Alarms.

plate *v* to the contact *n*. As often as the latter comes in connection with the spring *o* a current passes over the lever *k*, and the bell *n*, to earth E, and thus returns to the starting battery, for the second pole of L B is also connected with earth. The current flowing through the relay R closes the circuit of battery O B and the Morse apparatus M. The action of the relay also causes the key F to fall, whereby the circuit of bell W is closed. The key T now allows the operator to re-connect the line with the earth, so that a signal may be sent back. As many as 100 of such systems of apparatus were in use in 1881, and they worked in a very satisfactory manner.

ELECTRIC CLOCKS.

Electricity is used in connection with clocks in three different ways: (1) To control distant clocks from one standard clock. (2) To regulate clocks that are independent of each other. (3) As the motive-power. The transmission of time from a standard clock was tried by Steinheil in 1839. Electric clocks have been constructed by Bain, Hipp, Arzberger, Bréguet, Winbauer, and others, Fig. 381 represents an arrangement by Bain. The standard clock is represented by the pendulum D, the wheelwork, etc., being left out of the figure. This pendulum has a copper spring at D, which glides over the copper plate C once in every second. By means of this contact arrangement the circuit of battery *z k* is closed once in every second. The clocks to be regulated are inserted in the circuit of the battery *z k* by means of electro-magnets, such as M in the figure. The current reaches the electro-magnets M, and causes the attraction of the armature *b*. A spring *g* is fastened at the lower end of the rod, which carries the armature and also the catch which catches in the teeth of wheel *e*. When the armature *b* is attracted by the magnet M the catch slides over one tooth of the wheel, and the magnet loses its force of attraction during the break of current which follows. In consequence of this the armature is drawn back by the spring *g*, and the catch moves the wheel one tooth forward. The safety catch fastened at the bottom of the wheel *e* prevents the other catch from going over more than one tooth at a time. Hence, the motion of the clock connected with M is not regulated by a pendulum of its own, but by the escapement attached to *b*, which releases and checks the wheel *e* synchronously with the motion of the pendulum D. The motion of the wheel *e* is transmitted in the ordinary way to the minute and hour wheels.

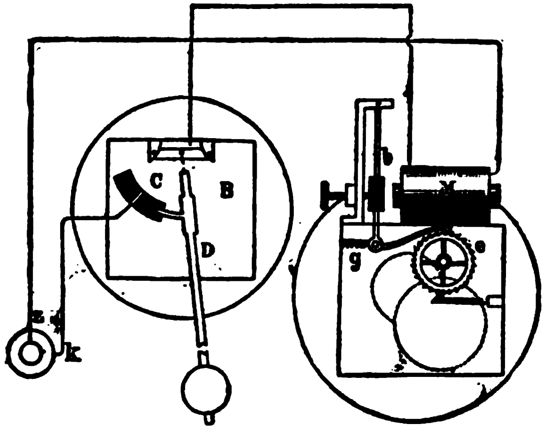


Fig. 381.—Bain's Clock.

Bréguet's Lantern Clock is shown in fig. 382; it possesses two electro-magnets E E, joined in series in such a way that their opposite poles face each other whenever a current flows through the coils. The permanent magnet A A, which is movable about V, is placed between these electro-magnets. The currents are sent through once every minute, and alternately in opposite directions. This causes the permanent magnet to move once to the right and once to the left every two mnutes. This motion is transmitted by means of the rod *t* to a system of catches *i i*, which move the wheel *c*, which in its turn moves the hour hand. The change of current which takes place every minute is brought about by a gyroscope, such as that shown underneath. The ivory cylinder *f g* is fastened upon the axis *t*, which is moved by means of a wheel with ten teeth through a certain angle every minute. The surface of

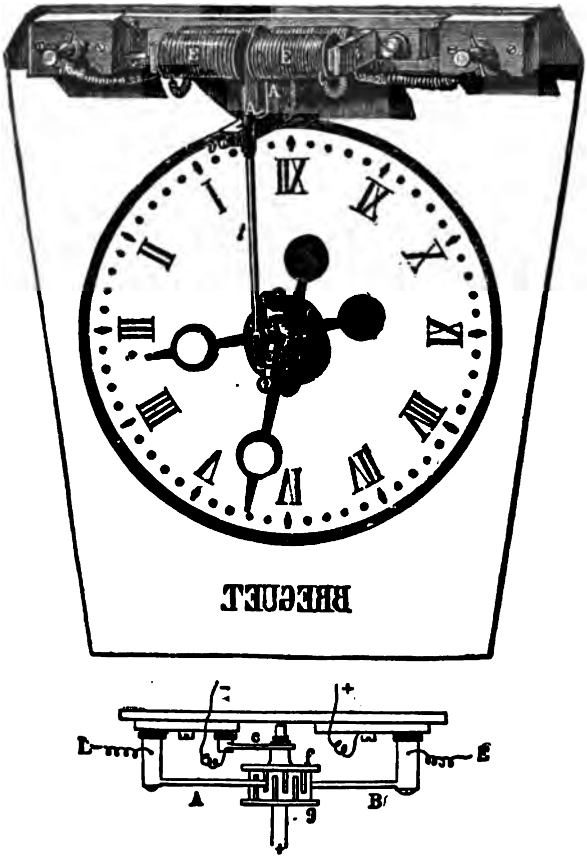


Fig. 382.—Bréguet's Clock.

this ivory cylinder is furnished with platinum pins, which alternately come into connection with the upper and the lower plate. The lower plate is fastened upon the axis *t* without insulation, but the upper plate is insulated from the axis, and stands connected by means of the spring *c* with the negative pole of the battery. The positive pole communicates with the non-insulated metal portions of the gyroscope, and also with the platinum pins of the lower plate *g*. The lines L and E are connected with the contact springs A and B, which slide upon the ivory cylinder. When the spring A is in connection with an upper platinum pin, and spring B with a lower platinum pin, the current flows from + through the axis *t* and plate *g*, to the lower platinum pin, through the spring A into the line, and then back to the negative pole over E B, and so to an upper platinum pin over *f* and *c*. During the next minute the ivory cylinder has moved so far that the spring A comes in contact with the next lower platinum pin, and the spring B with the upper platinum pin. The current has now to flow in the opposite direction through the line, viz., from + over *t* and B into the line *c*, from which it returns at L, and then passes over A, *f*, and *c*, and finally reaches the negative pole.

Synchronized and Sympathetic Clocks.—By means similar to those just explained, one standard clock, in whatever way regulated, may, by means of magneto-electric currents, convey absolutely isochronous movements to any number of affiliated clocks at any distance. Clocks which possess works of their own, and are only connected between certain intervals by means of electricity, are termed secondary clocks; or, when the connections take place regularly every hour, the arrangements for making them are called hour regulators. The hour regulator by Barraud and Lund, which is distinguished by its simple construction, is shown in fig. 383. The vertical electro-magnet *m m* possesses an armature, which is movable about *f*, and which has the weight *g* attached to one end, and a bar to the other end. This bar terminates in the two pins *r r'*; these pins catch in the slits *s s'* of two movable angular pieces *s p*, *s' p'*. (For the sake of distinctness, *r r'* has been represented in the figure so as not to catch *s s'*.) As long as no current flows through the coils of the electromagnet, the pins *p p'*, which reach through an opening of the clock-face at O, remain at the ends of the circular hole. The minute hand can, therefore, pass under the first pin. When, now, the minute hand is close to twelve, the current is closed by the standard clock. The magnet *m m* attracts its armature, and the pins *r r'*, which slide in the slits *s s'*, move the angular pieces, so that their ends cross like the blades of a pair of scissors. The two pins will, therefore, catch hold of the minute hand and place it exactly at twelve. The current is now broken, and the pins *p p'* are drawn again to their former position by means of weight *g*.

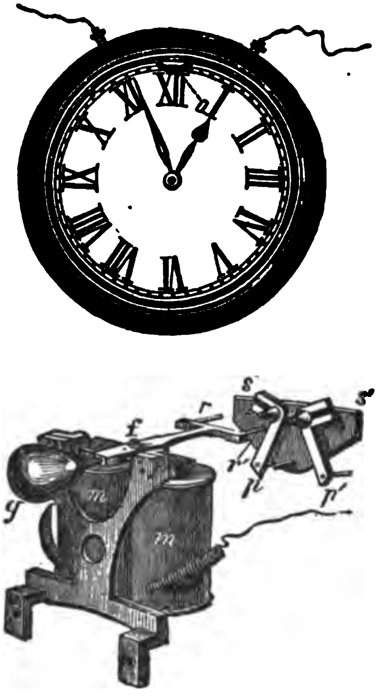


Fig. 383.—Barraud and Lund's Regulator.

Hipp's Connecting System is represented in fig. 384. The plate *n* carries the vertically arranged electro-magnet o_1, the armature p_1 of which is movable about the fulcrum q_1. The hook r_1 of the armature lever holds the lever s_1, which is movable about the fulcrum t_1, in the position shown in the drawing, as long as no current flows through the coils of the electro-magnet. The lever s_1 has at u_1 a block with a V-shaped incision, and the wheel x_1 has a pin attached to its front side at v_1. When the armature p_1 is attracted by the electro-magnet o_1 the lever s_1 is released, and the block u_1 falls upon the pin v_1; then the wheel x_1 is moved a little forward or backward, according as the clock is fast or slow,

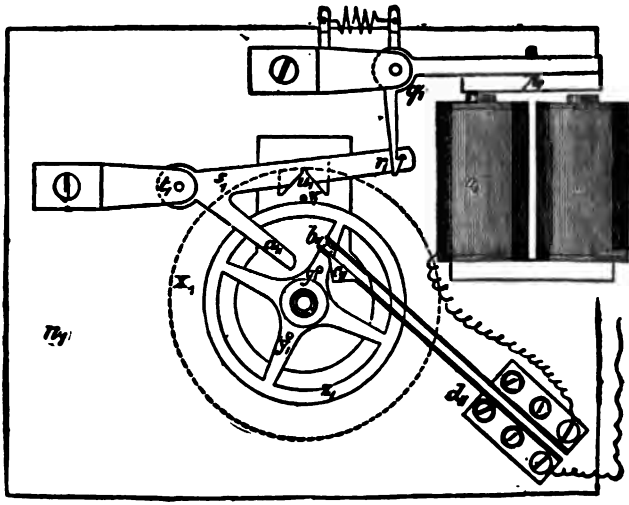


Fig. 384.—Hipp's System.

and the hands are thus made to mark twelve o'clock exactly. The block u_1 is so cut that it can catch the pin when it is as much as five seconds before or behind time. When the pin y_1, which is fastened upon the hour wheel z_1, comes under the projection a_{11}, the lever s_1 is brought into its former position again. A regulator, which furnishes a current at regular intervals, is used as a standard clock. If the current is required to act only every six hours, the two contact springs b_{11} and d_{11} are inserted in the circuit. The current therefore will only reach the coils of the electro-magnets when the two springs touch each other at b_I. This happens only twice during the complete revolution of the hour wheel, that is, when one of the two pins y_I y_I presses against the projection c_{II} of the spring d_{II}. This system is chiefly intended for the regulation of electrical clocks which are furnished with pendulums, and for translation regulators for clocks connected in an extensive network.

Hipp's Electrical Clock Pendulum is shown in fig. 385. The pendulum has a peculiarly constructed armature, which is designed to make the current in an electro-magnet only when it is required. When the arc of oscillation diminishes beyond a certain mark, the circuit of the electro-magnet is closed, and the armature at the lower end of the pendulum is attracted, and gives a new impulse to the pendulum. The current, of course, has to be broken before the armature comes opposite the poles of the electro-magnet, that is to say, before the pendulum passes the

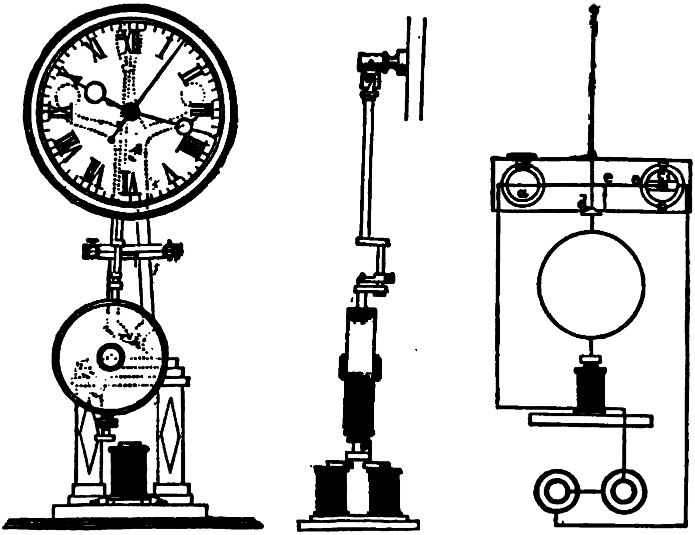


Fig. 385.—Hipp's Electric Pendulum.

vertical and the armature begins to leave the magnet. The break and make of the current is managed in the following manner: The prism *d* is fastened on the pendulum rod, about the middle of its total length; *c* is a spring, one end of which is fastened at *a*, while the other end is free, and rests upon an agate point at c_1, and a little steel plate, called the "palette," is suspended from the spring *c*. Above it is a screw which is connected with one pole of a battery, while the other pole is connected with the spring *c*. The current is made, and the electro-magnet is excited every time the spring *c* touches the upper contact at c_1. The pendulum rod and the palette *e* are in the same vertical plane, and, in order that it may be able to oscillate, the pendulum rod is arranged at this point as shown in the figure, that is to say, it is bent at right angles. As long as the arc of oscillation is sufficiently large, the prism passes underneath the palette *e*, and the spring *c* remains upon the agate point; but when the arc diminishes *e* catches in a groove of the prism, and lifts the spring *c*, thus making contact at c_1, and closing the circuit. The magnet then attracts its armature, and gives a new impulse to the pendulum; when the latter moves on under the influence of this new impulse, *e* slides down again from the prism *d*, and breaks the current. The attraction of the magnet now ceases, and the pendulum continues to oscillate. The number of times the current is made during a certain time depends upon the strength of the battery and the resistance of the electro-magnet. Doppler observed that when two newly-fitted Leclanché elements were used, at first the current was made every forty seconds, but after some months it was made every twelve or eighteen seconds, without the clock showing any irregularity.

Electrical Watchman-Clocks are used to show whether the watchman of a factory, theatre, etc., really makes his rounds at the appointed time. These control clocks consist in principle of a clock which keeps good time connected with an electrical registration apparatus. The watchman causes the time of his passing to be registered by depressing the keys which are arranged at certain places on his beat.

The apparatus constructed by Hipp for this purpose is shown in fig. 386. Let us suppose that the apparatus is intended for

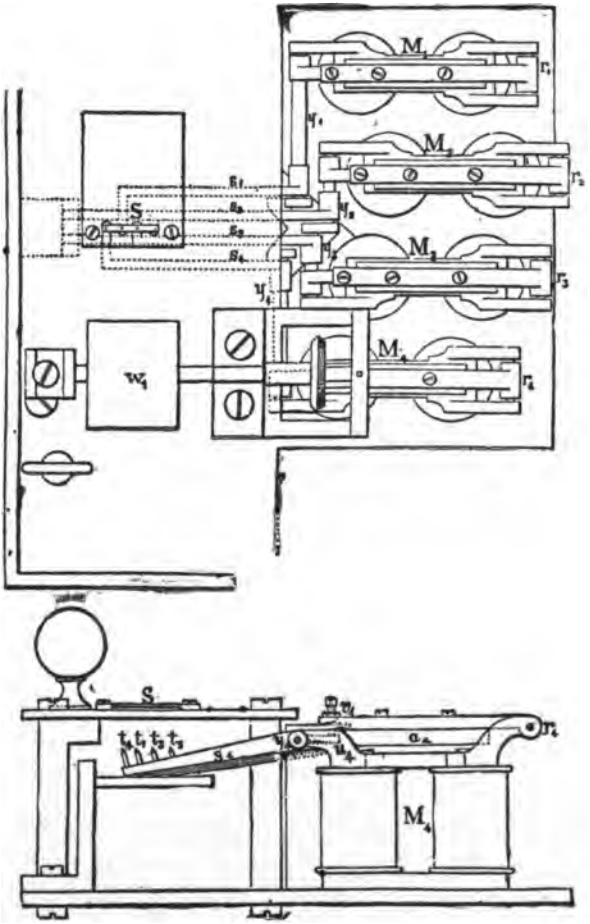


Fig. 386.—Hipp's Watchman-Clock.

four controlling places. In the lower portion of the clock case are the four electro-magnets M_1 to M_4, each of which has a movable armature; M_4, for instance, has the armature a_4 which moves about the fulcrum r_4. This armature is adjusted by the screw v_4, which rests with its point upon the two-armed lever s_4, which is movable about a fulcrum at y_4. By depressing the key of the electro-magnet M_4, the magnet is made to attract its armature a_4, and thus to depress the short arm u_4 of the lever. The other arm s_4 is, therefore, raised, and the pencil t_4 that the lever carries is pushed through the slit which is above it. The writing levers belonging to the remaining electro-magnets are bent in such a manner that their pencils may be pushed through the slit S parallel to each other. Above the slit moves a strip of paper, the breadth of which depends upon the number of electro-magnets or controlling places. The paper is kept in motion by the wheelwork of the clock. When the watchman makes his rounds at the time arranged, he depresses the different keys, and by this means marks the paper. To determine the time at which the marking took place, the paper strip is ruled with thin and thick cross lines; the former indicate quarters of an hour, the latter hours. A round of an hour, during which four stations have to be visited, would show the marking represented in fig. 387.

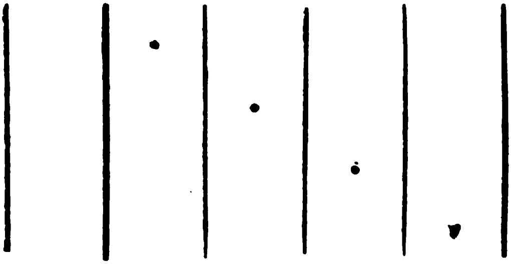


Fig. 387.—Register of the Clock.

Electric registration clocks are intended to allow an observer to register the instant of an event occurring. In one form of this clock the observer starts the apparatus at a given time, and thus puts a strip of paper in motion as in Morse's telegraph. A dot is then imprinted on the paper every second by means of a simple connection with an astronomical clock, or the paper is ruled for hours and minutes and wrapped on a roller turned by the clock. A separate marking apparatus, under the control of the experimenter, by simply making contact by pressing in a key, enables him to interpolate a dot or mark corresponding to the instant of any event happening—such, for instance, as the transit of a star. This method has the advantage of leaving the observer at entire liberty to watch the object without having to attend to the beats of the clock, whilst it renders mistakes next to impossible. It has been successfully applied to the determination of longitudes, and more recently to all kinds of astronomical observations, by Mr. Bond, in America, and by Sir G. Airy, at Greenwich.

Electric chronoscopes are instruments for the measurement of excessively short intervals of time, such as the flight of military projectiles, and even the transmission of sensation and motion along nervous fibres. Such instruments have been constructed on a great variety of principles. Those of M. Pouillet, Mr. Wheatstone, and Mr. Siemens deserve especial mention.

RAILWAY SIGNALLING.

Railway Station Signals.—Fig. 388 represents an arrangement of bell-signals, called the "Double-bell;" G_1 and G_2 are two bells; H_1 H_2 the hammers belonging to them. Each hammer is pressed towards the bell by a spring *f*, but is prevented from touching it by a more powerful spring F. The hammers move about the pivots X_1 X_2. When the wire Z is pulled, and then suddenly let go again, the weight of the hammer overcomes the spring *f*, and strikes against the bell; it cannot rest here, however, because it is immediately lifted off by the more powerful spring F.

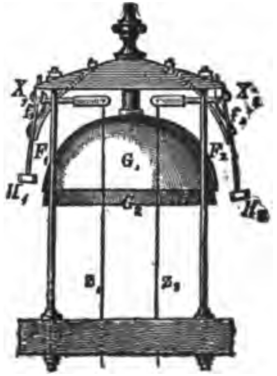


Fig. 388.—Double Bell.

The wires Z are connected with clockwork. The clockwork frequently used in France and Austria for line-signals is that by Leopolder, shown in fig. 389. The motive-force is supplied by a weight which causes the shaft T to revolve by means of the rope *t*. The wire that communicates with the bell is fastened to the arm Z of the lever Z Z_1, the arm Z_1 of which is lifted by the pins *r* of the wheel R whenever the catch is pulled back, so as to liberate the wheel. This is effected by means of currents sent into the coils of the electro-magnet M M and a system of jointed levers H_3 N and *c*. The armature A is fastened to the shaft X by means of *h*, and when it is attracted the shaft X moves through a small angle, and with it moves also the angular piece G, which is fastened upon it. This releases the spur *e*, which rested on G, and consequently *e* falls between *p* and *q*, and H_3 catches with its pin *y* the lever N, which moves about O. The projection *c*,

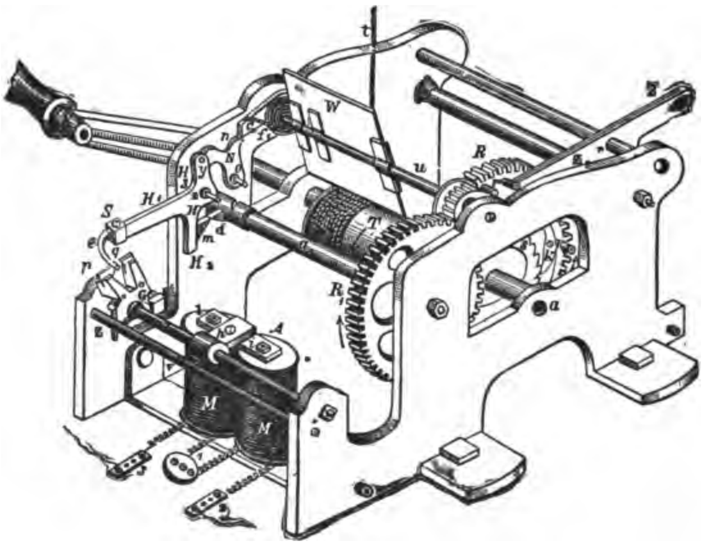


Fig. 389.—Leopolder's Signal Clockwork.

which rests upon *n*, is connected with the spiral springs *f* and *w;* the fan W rests upon shaft *u*, which is connected with the remaining wheels of the clockwork by means of a toothed wheel. When, therefore, *c* loses its position upon *n* in consequence of the magnetic attraction of the armature, the axis of the fan, and with it the whole clockwork, is set free, and the signal is given. The clockwork is stopped, when the current is broken, in the following manner: The shaft a_1 is moved by the wheel R_1 in the direction indicated by the arrow, and lifts the pin of the lever H by means of its own pin *d;* H_1 is also lifted, and *e* is again placed upon the plates *p* and *q*. The motion of the lever H is transmitted to H_3 and the lever N, and *c* again rests upon *n*.

As the signal line has frequently to be utilized for correspondence by means of a Morse apparatus, the connection of the different instruments with each other and the line has to be arranged accordingly. As an example of such a system of connection, we may take that of the Austrian Northwest Railway. The lines of the signalling apparatus have constant battery currents flowing through them, and are connected with the earth at almost every station. When a current arrives at the station by the line L_1 in fig. 390, it will take the following direction: Through the lightning plate P into the signalling apparatus N, through the key S into the relay R, thence over the key T and the galvanometer G to earth. The commutator *e d i* is connected with the relay R, and is generally so arranged that it closes the circuit of the local battery B_1 over the alarm W. When it is intended to correspond, the local circuit is closed, and this has the effect of inserting the writing apparatus M. The relay remains permanently inserted in the circuit before it acts; the spring of the relay armature has such a tension that the relay does not require the current to be completely broken, but lets go its armature when the current is only weakened. The springs, however, of the bell apparatus N N_1 have only a very feeble force of attraction, so that the magnets let their armatures go only when the current is completely broken. The keys T T_1 are so arranged that by depressing them the current is not broken, but a resistance is inserted in the circuit, so as to reduce the strength of the current. Hence, the mode of action of the total arrangement is as follows: When the Morse key T of a station is used in the ordinary manner the line currents are weakened, and have no effect upon the armatures of the magnets of the bell apparatus, but affect the relay R of the second station, and the message sent from the first station is reproduced

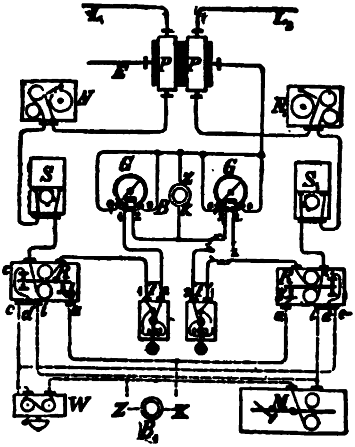


Fig. 390.—General Scheme of a Station.

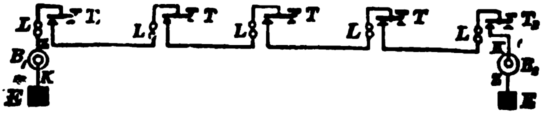


Fig. 391.—Connections of Signalling Instruments.

by means of the writing apparatus M. When, however, by means of the automatic key S, the currents are broken, all the signalling apparatus of that line is brought into action.

Several methods have been suggested by means of which the several signalling instruments on a line may be connected. The method of joining most frequently used to secure a constant current in the line shown in fig. 391; L indicates the signalling apparatus; B_1 and B_2 the batteries. The battery B_1 has its zinc pole Z joined to the line, and the battery B_2 its copper pole K, so that these batteries and the inserted apparatus have a constant current circulating through them when at rest.

THE TELEPHONE.

Reis's Telephone.—It was discovered by Page, in 1837, that an iron bar, when magnetized and demagnetized at short intervals, emits sounds; and on the basis of this experiment Philip Reis constructed his first telephone. Philip Reis was born on the 7th of January, 1834; he received a good elementary education, and entered a business-house when 16 years of age, but for some years devoted his leisure time to the study of mathematics, chemistry, and physics, attending lectures delivered at the commercial institute. He left business, however, and entered Dr. Poppe's establishment at Frankfurt, to qualify himself for a teacher. The first apparatus made by Reis, according to Dr. Messel, consisted

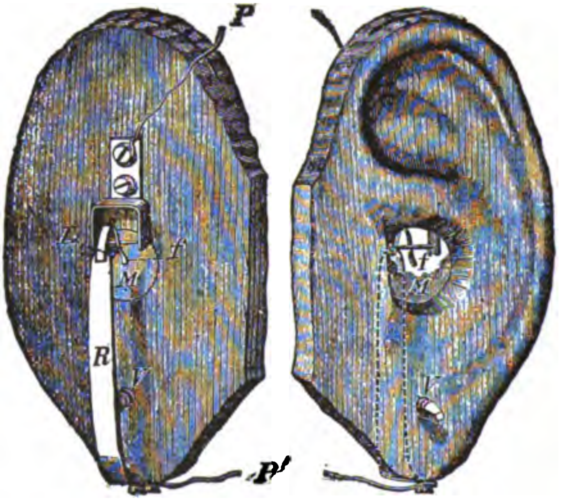
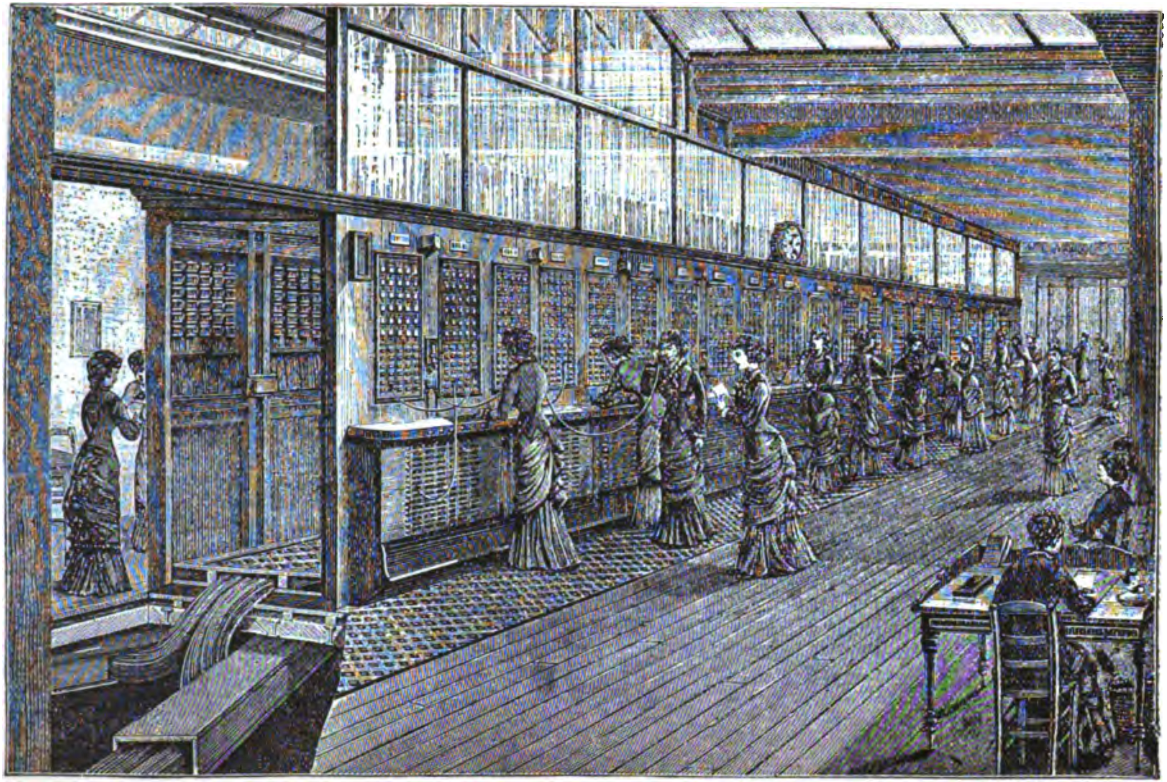


Fig. 392.—Reis's Telephone.



CENTRAL TELEPHONE OFFICE IN THE AVENUE DE L'OPÉRA, PARIS. (To face page 740.)

of a beer-barrel, in the bung-hole of which a small cone was placed, covered at its smaller end with an animal membrane, upon which a small platinum strip or wire was fastened by means of sealing-wax. The receiver consisted of a violin, upon which a knitting-needle, having a coil wound round it, was fastened. The receiver was afterwards made in the form of the human ear (fig. 392). Here the platinum wire *f* was fastened to the membrane M, and to the spring R, by means of sealing-wax, and a platinum contact L was placed opposite *f*. A screw V adjusted the spring. The wires P P′ connected the apparatus with the battery. When sound-waves made the membrane M vibrate, the circuit P *f* L R and P′ was made when *f* and L touched each other, and broken when they parted. The last modification of the apparatus is shown in fig. 393. It consists of three parts, A (the

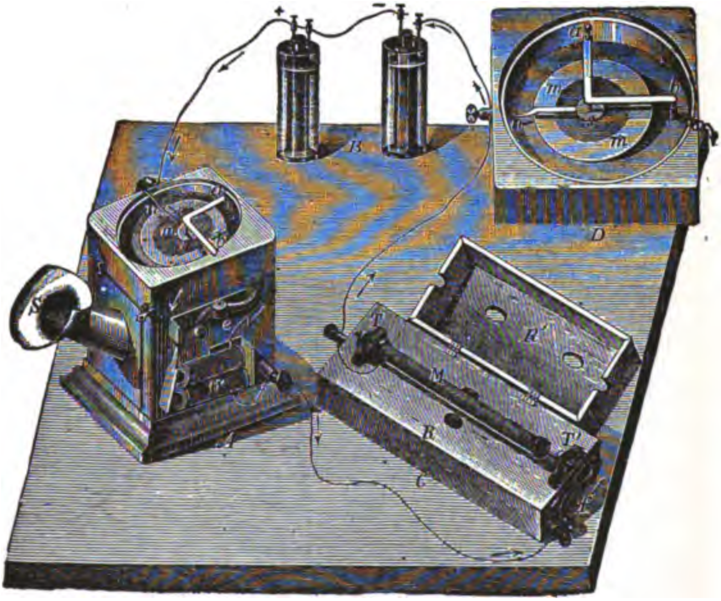
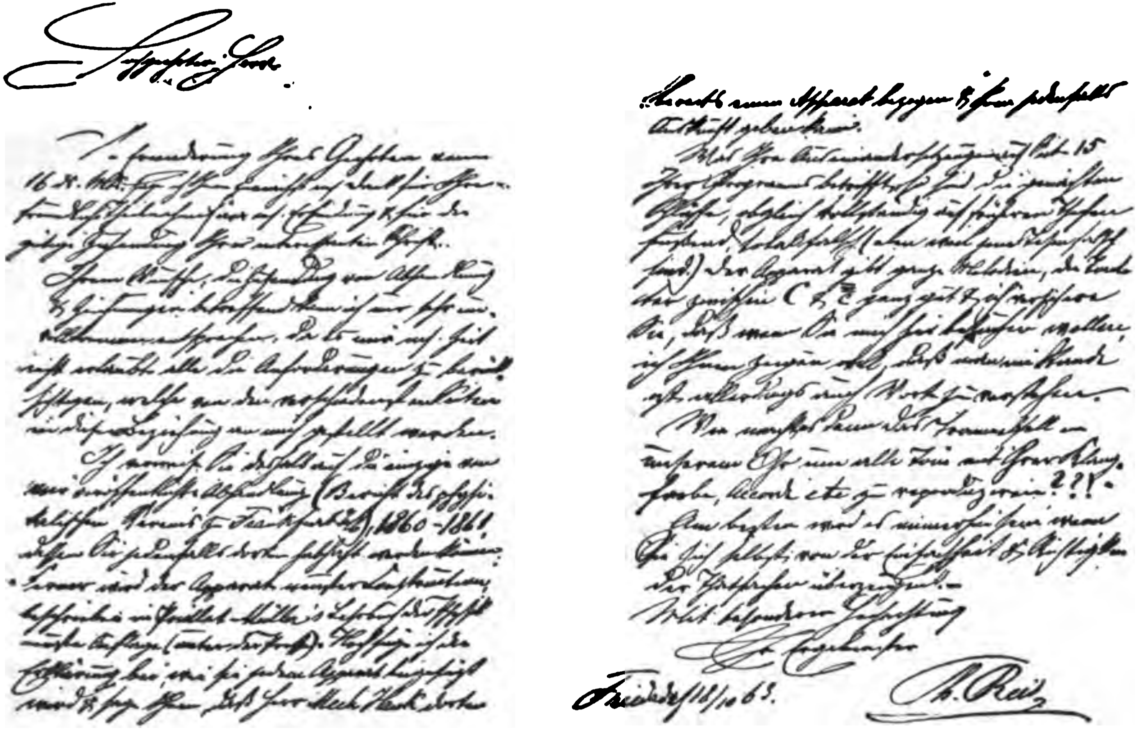


Fig. 393.—Reis's Telephone.

sender), B (the battery), C (the receiver). These three portions are connected with each other by means of wires. The upper portion of A is shown separately at D. *m m* is the tympanum of stretched membrane, having attached to it *n s*, the platinum strip. When the membrane vibrates, in response to the impulses of sound, this elastic strip of platinum beats to and fro against a tip of metal, altering the degree of contact at each vibration. The angular piece *a b*, which carries the contact-tip, is made of brass, and dips at *b* into the mercury-cup, to which the battery wire is brought; the receiver C consists of an iron needle, 21.5 centimetres long and 0.9 millimetre thick, round which the coil M is wound. The rapid magnetization and demagnetization of this iron wire produced sounds having the same frequency, and therefore the same pitch, as the note sung into the transmitter. Reis showed his apparatus for the first time to the Physical Society of Frankfurt in 1861. Much has been said and written as to whether Reis's telephone was capable of transmitting words, or sounds only. That it transmitted words is proved by the following letter, on opposite page, which Reis wrote to F. J. Pisko.

From this letter we translate the following extract: "The apparatus gives whole melodies in any part of the scale between C and c''' well, and I assure you, if you will come and see me here, I will show you that words also can be made out." Reis was well aware of the importance of his invention, which, at that time, was treated as a toy. He remarked to Garnier "that he had shown to the world a road to a great discovery, but left it to others to follow it up." Reis died in 1874. Although the priority of the German inventor, Philip Reis, cannot be disputed, Reis's telephone had to undergo many modifications before it could be utilized for practical purposes. S. Yeates (1865), Wright (1865), C. Varley (1877), C. and L. Wray (1876), E. Gray (1874), Van Der Weyde, and Pollard and Garnier, all tried to bring the telephone to a state of greater perfection. The singing condenser, simplified by Pollard and Garnier, is shown in fig. 394; *d d* is the condenser, consisting of tin foil placed between pieces of paper. The transmitter consists of a



Geehrter Herr!

In Erwiderung Ihres Geehrten vom 16. X. 1863 sage ich Ihnen zunächst meinen Dank für Ihre freundliche Theilnahme für meine Erfindung & für die gütige Zusendung Ihres interessanten Werkes.

Ihrem Wunsche, die Einsendung von Abhandlung & Zeichnungen betreffend kann ich nur sehr unvollkommen entsprechen, da es mir meine Zeit nicht erlaubte alle die Anforderungen zu berücksichtigen, welche von den verschiedensten Orten in dieser Beziehung an mich gestellt wurden.

Ich verweise Sie deshalb auf die einzige von mir veröffentlichte Abhandlung (Bericht des physikalischen Vereins zu Frankfurt a/M 1860–1861) deßen Sie jedenfalls dort habhaft werden können; ferner wird der Apparat meiner Construction beschrieben in Pouillet-Müller's Lehrbuch der Physik neueste Auflage (unter der Presse). Hierbei füge ich die Erklärung bei, wie sie jedem Apparat beigefügt wird & sage Ihnen, daß Herr Mech. Albert dahier [illegible] vom Apparat beziehen & Ihnen jedenfalls Auskunft geben kann.

Was Ihre [illegible] auf Seite 15 Ihres Programmes betrifft so sind die [illegible] obgleich vollständig auf früheren Versuchen fußend, total falsch (aber auch [illegible]) Der Apparat gibt ganze Melodien, die Töne zwischen C & c̄ ganz gut & ich versichere Sie, daß wenn Sie mich hier besuchen wollen, ich Ihnen zeigen will, daß [illegible] ist allerdings noch [illegible] zu verbessern.

Wer möchte denn das [illegible] an unserem Ohr um alle Töne mit ihrer Klangfarbe, Accord etc zu reproduciren ??!

Am besten würde es mir erfreulich sein wenn Sie sich selbst von der Beschaffenheit & Richtigkeit der Thatsachen überzeugten. —

Mit besonderer Hochachtung

Ihr ergebenster

Friedrichsdorf 13/11 63.

Ph. Reis

wooden ring, which is closed by means of the thin iron plate *c c*, over which the mouthpiece *e* is arranged; K, the contact-piece, consists of retort coke, and is fastened immediately opposite the narrow opening of the mouthpiece, *i. e.*, in the centre of plate *c c*. K$_1$, of the same material, can be adjusted by means of the screw V and wooden bar *h*. When the iron plate *c c* is at rest, K K$_1$ do not touch each other, but they will make contact on the slightest vibration of the plate, allowing the current of the battery B to pass. This battery consists of six Leclanché elements.

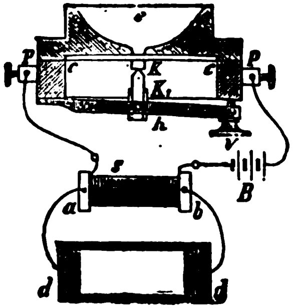


Fig. 394.—Pollard and Garnier's Singing Condenser.

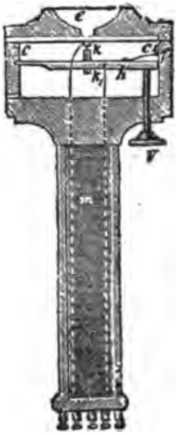


Fig. 395.—Janssens' Telephonic Apparatus.

One of the clamps *p* is connected with K, and the other *p'* with K$_1$. One pole of the battery is connected with one of these clamps *p'*, the other with the primary coil of the induction spiral S. From the copper fastenings of the condenser the wires lead to the secondary coil. When the plate *c c* is made to vibrate by singing into the mouthpiece *e*, vibrating currents are sent through the primary spiral, causing similar induced currents in the secondary spiral. The condenser then begins to sound, imitating the singer more or less closely.

Janssens' Modification of Reis's Telephone.—A further simplification of the apparatus, given by Janssens, is shown in fig. 395. The transmitter is enclosed in a wooden box, ending in a tube, which has the induction spiral *m*; *c c* is the iron plate; K and K_1 the two carbon pieces, and *w* is the lever carrying the lower carbon piece; *v* is the screw, *f* a spring for adjustment. In order to allow the air enclosed in the box to vibrate freely, holes are cut in its side.

Bell's Telephone.—We shall now consider the magneto-electric telephone, as constructed by Graham Bell. Mr. Bell came to Boston in 1868 as a teacher of the deaf and dumb. The deaf and dumb are not, as a rule, unable to speak because their organs of speech are defective, but because, in consequence of their deafness, they cannot hear the spoken word, and therefore cannot imitate it; it is, therefore, usual to teach them to speak through other agents than the ear. For the further development of this method, Graham Bell and his father, Alexander Melville Bell, studied the mechanism of the voice. Graham Bell produced vowels artificially by means of tuning-forks, and, aided by Helmholtz's investigations (1859—1862), he made use of the electric current for his experiments. The first form of Bell's telephone is shown in fig. 396. A stave harmonica H H′ is fastened to the poles of the permanent magnet N S, and between H

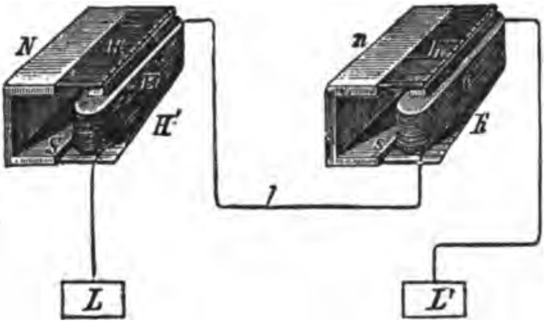


Fig. 396.—Bell's Electric Harmonica

and H' a coil of wire, surrounding a soft iron core, is placed. An exactly similar instrument is formed of a second permanent magnet *n s*, and the ends of the two coils E and *e* are connected either by two lines or by one line wire *l* and the earth L L'. When any one of the staves H is made to vibrate—that is to say, to approach or recede from the core E—it will strengthen and then weaken the induced magnetism of E, and, as a consequence, currents will be induced in the coils of the electro-magnet E. The currents will flow through the coil of the second electro-magnet *e*, connected by means of the wire *l* and the earth-plates L L' with the first. Therefore, one of the staves *h* upon the permanent magnet *n s* will be attracted and repelled, *i. e.*, will also begin to vibrate; but the impulses which the electro-magnet *e* receives are exactly the same as those induced in E through the vibrating of the stave; consequently *h* will have the same vibration. Further, each stave can only produce that vibration peculiar to it, and of the staves in *h* only the one will continue to vibrate whose natural rate of vibration synchronizes with the impulses corresponding to the stave in H. If each prong of H be struck in succession, the prongs in *h* which are in unison with those of H will sound in succession; and if a tune be played on the prongs of H, the same tune will be heard from *h*.

The expense of such an apparatus prevented Bell from developing and perfecting this idea. He, however, investigated the different kinds of vibration obtained through different effects of current, and was led to distinguish between three different kinds of currents. Let us assume that the body which is to be made to vibrate is an iron plate, and the body causing the vibration an electro-magnet. If the latter be magnetized and demagnetized by the making and breaking of the current in quick succession, Bell calls this current an intermittent one. If care be taken that a distinct, although weak, current flows through the circuit, which is weakened and strengthened by the approach and recession of a magnet, then this current is called by Bell a pulsating current. These two kinds of current were made use of in the older telephones. Plates set in vibration by these methods trace out undulations which, when represented graphically in the indicator diagram, show angular lines corresponding to the sudden make or break of current. But the human voice consists of continued sounds and noises, and it is therefore evident that neither by means of the pulsating nor of the intermittent currents will words be thoroughly reproduced. Speech can only be reproduced when exactly the same vibrations can be obtained at the place where the reproduction has to take place. For this purpose Bell uses currents which he calls undulating currents, the characteristic of which is that they increase and diminish, not abruptly, but gradually. Indicator diagrams obtained with these currents show wave-shaped lines, which rise and fall gradually. Undulating currents are, therefore, capable of copying the human voice, as they can excite short and quick, as well as long and slow waves.

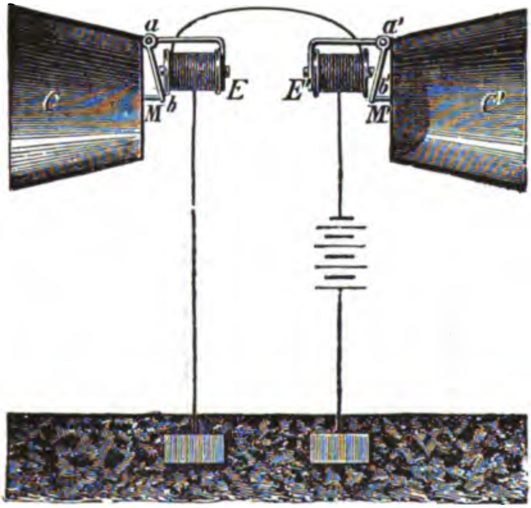


Fig. 397.—Bell's Second Telephone.

Bell's Second Telephone.—The next apparatus that Bell constructed is shown in fig. 397. The cone c had its smaller opening closed by means of a gold-leaf M, which was connected by means of a little rod with the armature *a b* of the electro-magnet E. The cone C′, exactly similar to the first, was fitted in a similar manner with membrane M′ and electro-magnet E′. When the membrane M, excited by sound-waves, began to vibrate, the armature, which vibrated along with it, induced undulating currents in E, which caused the same vibrations on the membrane M′ by means of the magnet E′, and its armature *a′ b′*. Bell took out a patent for this form of apparatus on the 14th of January, 1876.

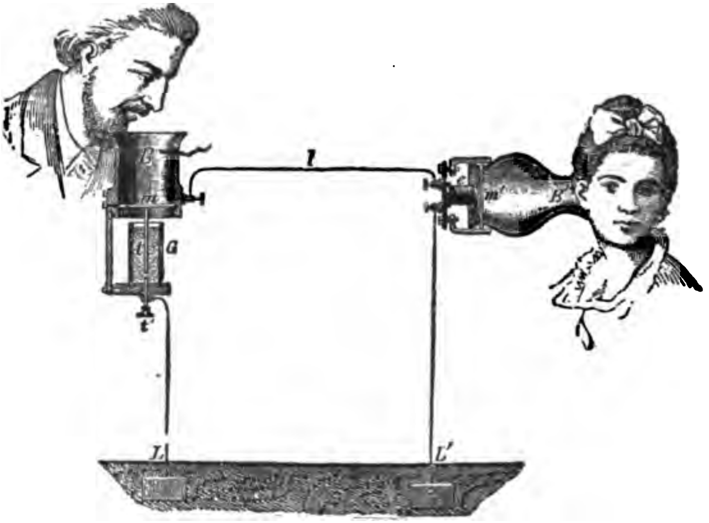


Fig. 398.—Gray's Telephone.

Gray's Telephone.—About the same time Elisha Gray's agent also requested a patent for a telephone. In Gray's telephone, shown in fig. 398, the sender and receiver are differently shaped. The membrane of the sender B has at its lower side the metal rod *t*, the continuation of which is formed by the screw *t′*. The rod *t* passes through a vessel G, which is filled with a bad-conducting fluid. The receiver consists of the vessel B′, which is closed at one side by the membrane *m'*. The membrane has a piece of soft iron attached to it in the middle, and opposite to this is placed the electro-magnet *e*. The two parts of the apparatus are connected with each other by means of the wire *l* and the earth-plates L L', and are inserted into the circuit of a battery. The membrane which is made to vibrate by speaking, inserts by means of the rod *t* more or less resistance in the circuit, producing, if we may use Bell's expression, pulsating currents, which are conveyed to the electro-magnet of the receiver, and cause the membrane *m'* to vibrate like the membrane *m*.

Bell and Gray disputed about this latter patent, and the dispute was decided in favor of Bell.

Bell's Third Telephone.—The results which Bell obtained with

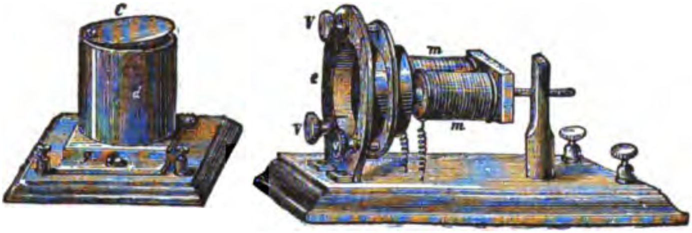


Fig. 399.—Bell's Third Telephone.

the apparatus represented in fig. 397 did not satisfy him, and his next step was to give the sender and receiver the forms shown in fig. 399. The former consists of the electro-magnet *m m*, placed behind a metal ring *e*, the screws of which V V serve to hold a parchment membrane in position before the magnet-poles. To the membrane is glued a plate of soft iron serving as armature for the electro-magnet. The receiver consists of a straight electro-magnet, which is surrounded by an iron tube *d*, the iron plate *c* of which serves as armature. This plate C is fixed on one side only; *g* is a resonance bridge placed between the ground frame and apparatus. When anything is spoken against the membrane of the sender, it vibrates with its iron plate, and generates undulation currents in the electro-magnet *m m;* these flow through the wires to the receiver, making the iron plate C vibrate in the same manner as the membrane of the sender.

The Bell telephone was exhibited at Philadelphia in 1876 in this form (fig. 399). Although satisfactory results were obtained with the instrument, it had the drawback that its receiver could only be used as a receiver, and not at the same time as a sender. Bell then constructed the apparatus which we shall describe after we have discussed another instrument now very commonly used as the "sender" in a telephonic circuit. The Bell telephone, in its final form, is capable of transmitting speech perfectly and exactly, provided the distance between the two stations be not too great.

The Microphone.—Before the telephone could be brought to the commercial importance, however, that it has at present, there was still a problem left to be solved, the solution of which was effected by the discovery of the microphone. Hughes, the inventor who first applied the name, gives, as the essential feature of the microphone, the presence of a conductor capable of changing its resistance with the sounding vibrations. The scientific principle, according to which the resistance is made to vary by the vibrating body, was discovered by Th. du Moncel in 1856. It may be stated as follows:—When an electric current passes through the point of contact of two bodies, the electric conductivity changes with the change of contact pressure of the two bodies. Carbon, which is especially adapted for contacts of varying resistance, was first practically made use of for telephony by Edison, in his carbon telephone, the description of which will be given later on.

Berliner's Microphone.—Fig. 400 represents a microphone for which E. Berliner, in Boston, took out a patent on the 7th of July, 1877. The apparatus at the receiving and sending stations is similar in construction, and each consists of a battery, an induction coil, and carbon contacts, to form a microphone. The secondary spirals of the induction coils J J′ are constructed by the wires L L′. The primary coils are inserted in the circuits containing the batteries B B′, and the carbon contacts S S′.

Dr. R. Lüdtge obtained a German patent on the 12th of January, 1878, for his "universal" telephone; but it would lead us too far to record here all the microphones that have been patented. Professor Hughes was the first who treated microphonic phenomena systematically, and is, therefore, considered to be the inventor of the microphone. His investigations were made known to the Royal Society of London in 1878.

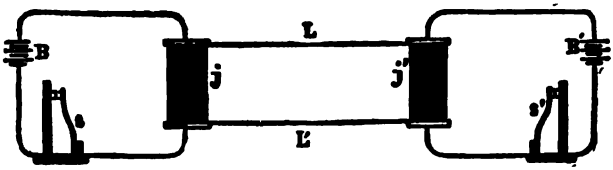
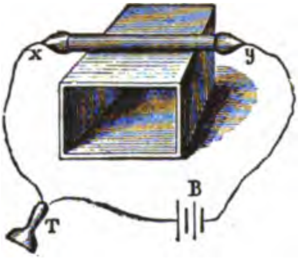


Fig. 400.—Berliner's Transmitter.

Hughes' Experiments.—We shall here find it convenient to describe some of the experiments made by Hughes in the process of perfecting and studying his invention under varying conditions. A glass tube of about 8 centimetres in length was filled with bronze powder, and the ends were closed by means of retort coke, so that the metal powder was gently pressed together. The wires fastened to the carbon plugs formed a closed circuit with a battery and a galvanometer. When a pressure or pull with both hands was exerted on the tube, the galvanometer needle showed a powerful deflection. The tube proved also convenient for producing a simple telephonic apparatus. For this purpose the tube was placed upon a resonance box (fig. 401), the plug *y* was connected with a battery B, and the plug *x* with a Bell telephone T. Words spoken into the resonance box could be heard distinctly in the telephone T placed at various distances. The same results were obtained when, instead of the glass tube, a rod of charcoal was taken, which had been previously brought to white heat, and then dipped in mercury. A still simpler arrangement tried by Hughes is that shown in fig. 402. It consists of two wire pins, placed parallel to each other, and a third one simply laid across them; the pins X and *y* are joined in the circuit. In this arrangement the contacts of the cross-pin with the pins underneath form the changeable resistance which brings about the microphonic effects.



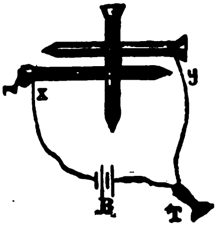


Fig. 401.—Hughes' Microphones without Carbon.—Fig. 402.

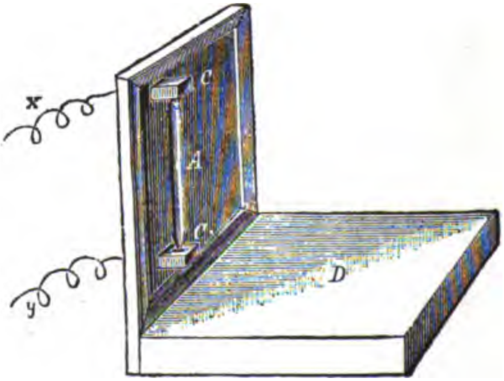


Fig. 403.—Hughes' Carbon Microphone.

Microphones of greater sensibility are shown in figs. 403 and 404. Upon the platform D, fig. 403, a resonance board is fastened vertically, and made to carry two carbon blocks C C, between which the carbon rod A is placed. The wires *x y* are fastened to the carbons C C. To experiment with this microphone, it is placed upon cotton-wool, or upon two pieces of india-rubber tubing. The wires *x y* are connected with a Bell telephone, and a battery consisting of one to two Leclanché or three Daniell elements. The vibrations of sound, when conveyed to the points of contact of C C and A, either directly, by the air, or through the board, alter the resistances at these points, and so strengthen and weaken the current alternately for every pulse. The changes of current will affect the magnet of the distant telephone, and reproduce the vibrations in the telephonic plate. The instrument is so sensitive that a fly walking across D can be heard through the telephone. Words spoken even at a distance of from 8 to 10 metres from the microphone are distinctly heard. As the efficiency of a microphone is greatly dependent upon the kind of contact, it is advantageous to make the latter so that it can be regulated. This may be easily brought about, in the manner shown in fig. 404. To ascertain the most effective position of the two carbons with regard to each other, a pocket watch, for instance, is placed upon the soundirg-box of the microphone; the ticking is observed through the telephone, and the two carbons are regulated by means of the screws until the best effects are obtained.

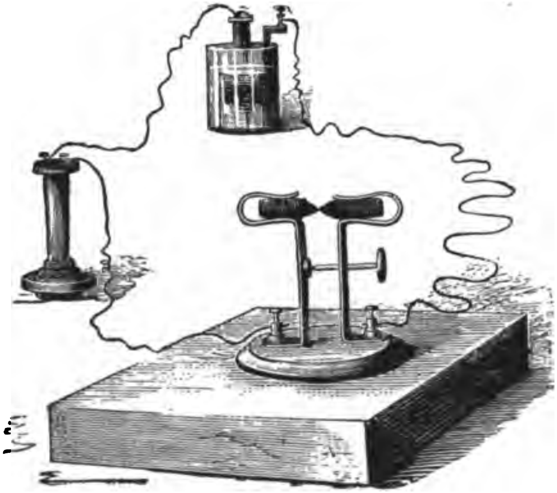


Fig. 404.—Hughes' Carbon Microphone.

So far we have had under consideration the historical development of telephony; we have now to consider the practical applications of these instruments.

BELL'S TELEPHONE AND ITS MODIFICATIONS.

Explanation of the Theory of the Telephone by Faraday's Lines of Force and Maxwell's Rule.—When a closed conductor is moved across the lines of force in a magnetic field, a current of electricity is generated whose strength depends upon the velocity of motion of the conductor and upon the intensity of the magnetic field. Conversely, when lines of force are projected through a closed conductor, a current of electricity is generated in that conductor, whose strength depends upon the magnetic intensity of those lines of force. In other words, when a closed circuit moves in a magnetic field so that the number of lines of force passing through the circuit is altered, then a current is produced in the circuit; and, conversely, when the closed circuit is stationary, but the field either moves or alters its form so that the number of lines of force projected through the circuit alters, then also a current is generated in the coil. The direction of the current is given by Lenz's law, viz., that the current produced tends to resist the motion producing it. The latter or converse form of the rule is the principle of the telephone, which proves that the form and duration of the current is dependent upon the rate and duration of the motion of the lines of force.

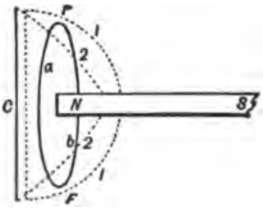


Fig. 405.—Theory of the Bell Telephone.

Let N S (fig. 405) be a permanent magnet, and *a b* a fixed closed conducting ring of copper wire around one pole of the magnet. Let *c* be a movable iron armature. Now, if we regard any two lines of force, F I F I, radiating from the pole N, and nearly cutting the ring *a b*, then, as we make *c* approach or recede from N, those lines of magnetic force will change their direction, taking up position 2; and with each change of direction they will cut the ring *a b*, and currents of electricity in different directions will circulate through *a b* according to the direction of motion of the lines of force; and the rate of increase and decrease of magnetic intensity (or of the increment or decrement of the current) will vary directly with the rate of motion of the armature *c* to or from the pole N. Thus if *c* be a disc of iron vibrating under the influence of sound, the excursions to and fro of any point of the disc, though very small, are nevertheless sufficient to produce that motion of the lines of force which results in currents. It bends the lines of force cutting *a b*, and thereby produces undulating currents of electricity in the ring *a b*, whose number depends on the number of vibrations, and whose form and intensity depend on the rate and amplitude of motion of the disc *c*.

These currents are alternate, and so rapid that no known instruments but the telephone indicate them; but they are readily shown by a Thomson's reflecting galvanometer, when the disc is gently and slowly pressed in by the finger—in one direction when the disc is pressed in, and in the other when it is allowed to recover its first form. The vibrations of thin discs under the influence of sounds can be made optically visible in many ways. One method is to stretch an india-rubber membrane over the end of a speaking-tube, with a small mirror cemented in the centre; on singing into the tube a spot of light reflected from the mirror will describe on a screen the most extraordinary figures. But a more perfect and beautiful method is to place across the end of the speaking-tube a plate pierced by a hole 30 to 40 millimetres in diameter, closed by a soap-film. On singing into the tube, all the vibrations can be seen in the film, producing the most intricate and complicated figures, which change with every note. Such an instrument is called a Phoneidoscope. Its figures may be readily projected upon a screen with the aid of a lantern, or may be seen with the naked eye in the film itself, and give a vivid idea of the complicated vibrations which take place in a thin plate under the influence of sound.

The ultimate form which Bell gave to his instrument is shown in fig. 406. *m* is a powerful bar magnet, encased in a wooden frame *f f*, the end of which is surrounded by the induction coil *b b*. The ends of the coil are soldered to thick copper wires *d d*, which terminate in the clamps V V. The distance of *m* from the thin iron disc *c c* can be regulated by means of a screw. The sheet of iron has that side which can be seen from *e* coated with varnish or tin to prevent oxidization. The strength and length of the wire for the induction coil must be proportional to the resistance which exists in the circuit of the telephone. The instrument acts best when the magnet is powerful, and the turns of the induction spiral are numerous, and when the iron disc is placed very near to the magnet. The distance has, however, to be arranged so that the disc, even in its most violent vibrations, does not come in contact with the magnet. For convenience in the handling of the instrument, the clamps V V are, as a rule, covered, as is shown in fig. 407. A mouthpiece *e* collects and concentrates the voice.

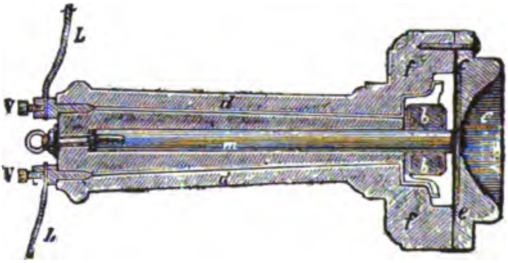


Fig. 406.—Bell's Telephone.

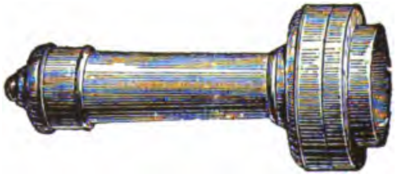


Fig. 407.—Bell's Telephone.

Bell's telephone may be used both as a receiver and a transmitter. Fig. 408 represents two Bell telephones which are exactly alike, each of which may be used either as a receiver or as a transmitter. *b b'* represent the induction coils, N S and N' S' the magnets, and *e e* the speaking-funnels with the iron discs.

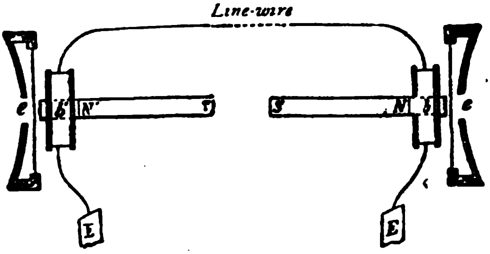


Fig. 408—Diagram of Transmitter and Receiver.

The ends of the coils are connected with the earth-plates E E on the one side, and with the line on the other.

It will now be understood that when the sheet-iron disc of a telephone is made to vibrate by speaking into it, the position of the sheet as regards the magnet will be continually changing; but the changes between magnet and sheet cause corresponding changes in the magnetism of the iron. The latter is surrounded by a coil *b*, which is connected with a similar coil *b'* in the same circuit. The current impulses produced in the coil *b* through the alteration of the magnetism of N S (or rather of the shape of the lines of force between N and the disc, whereby a larger or smaller number pass through *b*) will, therefore, be conveyed through the whole circuit, and will appear at the receiving station in the coil *b'*—hence, the iron sheet at the receiving station will vibrate, and exactly copy the sound-waves at the sending station. The nature of these vibrations is fully explained in the work of Th. du Moncel, *Le Télephon.* The circuit offers a resistance to the current impulses, and so weakens them, and this is why the words sound indistinct, as if coming from a distance.

The object which the improvers of Bell's telephone have had in view is to reproduce words at a receiving station placed at a considerable distance from the telephone. Bell constructed telephones which were specially designed for this purpose, by using which it was possible to hear music, at all events, in all

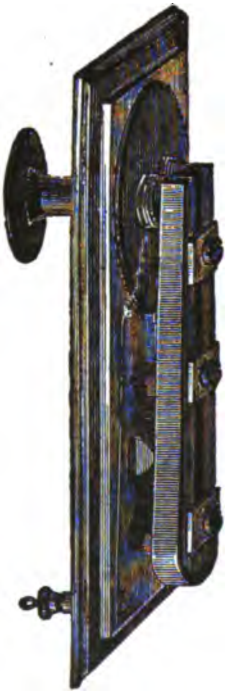


Fig. 409.—Bell's Telephone.

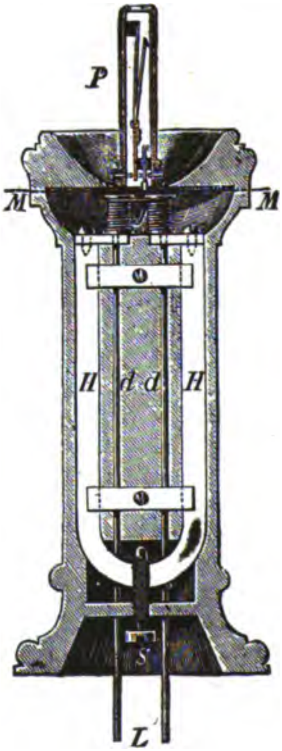


Fig. 410.—Siemens' Telephone.

parts of a moderately large room. One of these arrangements is shown in fig. 409. In the lid of a box (left out in the figure) a circular hole is cut out, and is covered by the sheet-iron disc. The latter has a thickness of from 0.4 to 0.8 millimetre, and is fastened by means of screws to the lid. The speaking-funnel (the tube of which must not be very short) is arranged opposite the centre of the sheet. The poles of a powerful horse-shoe magnet are opposite the other side of the sheet. The poles are prolonged by iron pieces directed vertically towards the sheet, each of which is surrounded by an induction coil.

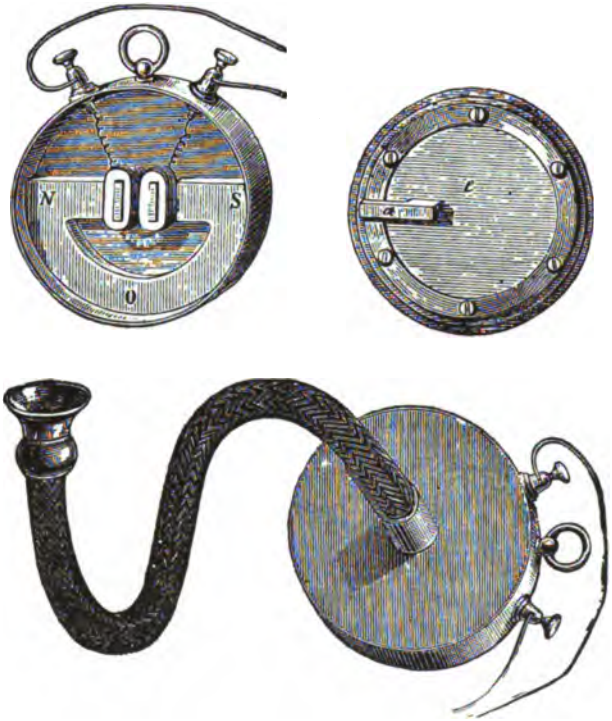


Fig. 411—Gower's Telephone.

Many attempts have been made to increase the effects still more. Niaudet, for instance, uses four iron pieces, and arranges the four coils in a square. Fig. 410 represents one of the modifications of Bell's telephone by Siemens. Here again the poles of a horse-shoe magnet are placed opposite the disc, so as to produce a more powerful effect than that of the single pole of a bar magnet. H H represents the horse-shoe magnet, J are the two induction spirals, and opposite these is the iron disc M M. The ends of the induction coils are connected with the copper wires *d d*, ending in the leads L. The position of the magnet may be so regulated, by means of the screw S, that its poles are in the most advantageous position as regards the iron disc. P is a whistle which is placed in the lower opening of the speaking tube, and may be used as a signal.

Gower's Telephone, which was at first thought highly of because of its extraordinarily powerful effects, is shown in fig. 411. The horse-shoe magnet N O S is bent into a semi-circle, and the ends of its arms are bent at right angles to the plane of the magnet. The bent portions carry the oval-shaped induction coils. The magnet formed in this manner is very powerful, and, according to Th. du Moncel, capable of carrying a weight of 5 kilogrammes. The ends of the induction coils are connected with clamps that are fastened to the outside of the metal box enclosing the apparatus. The sheet of iron *e* is larger and made of stronger material than is generally used for telephones. The signalling apparatus consists of the tube *a* bent towards the iron sheet, inside which a small vibrating tongue is placed; this can be agitated by blowing into the flexible tube, through the mouthpiece fastened to the back of the case.

The telephone by W. Fein, of Stuttgart, shown in fig. 412, is similar to the apparatus just described. The horse-shoe magnet *m* is so arranged that only the poles are inside the telephone case. The iron cores are arranged at right angles to the plane of the magnet, and in order to make them more sensitive to the effects of the currents, they are made of thin plates or wires. The cores as well as the coils *b* surrounding them have semi-circular sections, so that their effects upon the iron sheet may be more regular. By adopting this form, both coils when put together have the same circular plane cross-section. The ends of the induction coils are connected with the clamps *p p*. The brass lever *f*, which can be made to affect the iron cores by turning the screw v, serves to adjust the telephone.

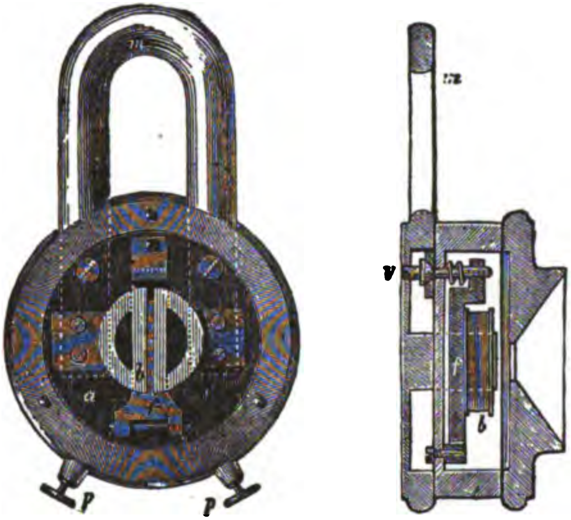


Fig. 412.—Fein's Telephone.

Ader's Telephone.—Cl. Ader constructed an effective telephone by making use of the principle that an iron plate inserted between a magnetic pole and its armature is affected inductively as if it formed part of the armature. We know that when a piece of iron is brought near a magnet it becomes magnetized by induction. That side of the armature which is nearest the north pole of the magnet receives south magnetism. If we now bring a thin iron plate between the magnet-pole and the armature, we find that the distribution of poles in the armature has not altered, and the lines of force pass right through the thin plate. According to the law of induction, that side of the plate facing the north pole of the magnet should show south magnetism, and so on. Experiments, however, such as the production of magnetic curves by iron filings, show that the thin iron plate between the north pole of the magnet and the south pole of the armature has exclusively south magnetism. This behaviour of iron plates may further be illustrated by the following experiment: A thin plate is brought before the poles of a powerful horse-shoe magnet, but at such a distance as hardly to be attracted by the magnet; if now an armature be placed before the magnet so that the iron sheet is between the magnet and the armature, the iron plate will be immediately attracted by the magnet. The effect obtained by means of the armature may be explained by supposing both sides of the sheet to have the same kind of magnetism. Similar poles stand opposite each other on the side of the armature, and repel each other, but dissimilar poles towards the magnet attract each other. The attractive force of the latter is aided by the repulsive force of the former, and therefore the disc moves towards the magnet.

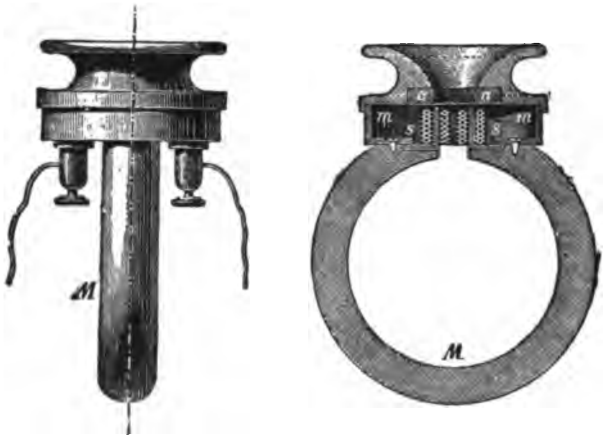


Fig. 413.—Ader's Telephone.

The apparatus shown in fig. 413 is constructed on this principle. The circular-shaped horse-shoe magnet M has the induction coils S S surrounding its pole-projections, and opposite to these the iron sheet *m m* is placed. *a a* is a ring of soft iron, which is placed inside the mouthpiece of the telephone, so as to form the armature of the horse-shoe magnet. The thin sheet is placed between the magnet-poles and the armature, and will therefore be exposed to strong magnetic influences. Ader rounds the magnet carefully off and then nickel-silver-plates it, to give to the apparatus a neat appearance and a convenient form.

D'Arsonval obtains a powerful effect by using a bell magnet. The magnet *m m*, fig. 414, is almost spherical; one of the poles has the cylindrical iron-piece *d* round which the induction coil *b b* is wound. The projection of the second pole has the form of a hollow cylinder, which surrounds the induction coil. The telephone by D'Arsonval weighs only 125 grammes, gives the words clearly and distinctly, and is said to surpass even Gower's telephone in force. In place of the usual speaking-funnel, a flexible tube is used, and in this manner sound disturbances are supposed to be overcome.

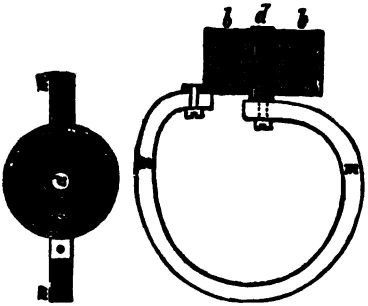


Fig. 414.—D'Arsonval's Telephone.

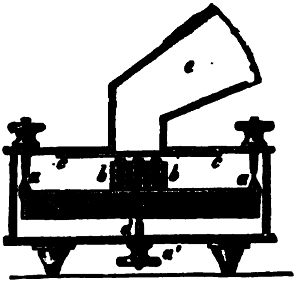


Fig. 415.—Böttcher's Telephone.

Böttcher's Telephone differs from other constructions by having the magnet so arranged as to be capable of vibrating; for this purpose it is suspended from fine steel loops. It can be moved upwards by means of the screws *a a*, fig. 415; downwards by screw *a'*. The cores upon which the induction coils *b b* are fastened do not consist of one piece, but of three separate iron bars, an arrangement which facilitates the change of magnetism. The case of the telephone consists entirely of metal, because wood is more liable to change, and to cause an alteration of the action of the magnet-poles towards the iron sheet. The tube *e*, which serves as a speaking-tube, is bent at an obtuse angle. The effect obtained with this instrument is very powerful; the sounds, however, are not so pure as in Bell's, Ader's, and other instruments. Böttcher's instrument would not answer in places which cannot be guarded from noises and disturbances.

Just as it has been attempted to increase the efficiency of telephones by increasing the number of magnets or magnet-poles, so also several vibrating plates independent of each other have been used. A telephone with two plates has been constructed by Elisha Gray; it consists (as shown in fig. 416) of two telephones placed at an acute angle. The horse-shoe magnet N *m* S has cylindrical shoes A at its poles, which are surrounded by the induction coils *b b*. Each shoe has a sheet of iron opposite to it, but the speaking-tube *e*, which terminates in the tubes *a*, serves for both membranes. The connection of the coils is shown at *d;* L L is the lid that covers the disc.

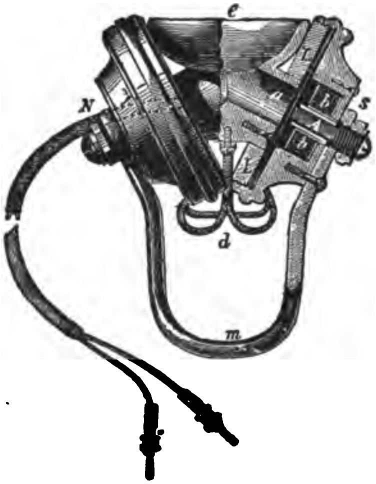


Fig. 416.—Gray's Telephone.

Phelps' "crown" instrument is shown in fig. 417. It has only one iron disc *c c*, opposite to which the similar poles of six ring-shaped magnets are placed; the remaining poles are bent against the edge of the disc. Phelps' double instrument consists of two telephones, such as described above, which are united to each other in such a manner that the two discs stand parallel to each other. The speaking-tube terminates in the space between the two discs. It was found, however, that the same results can be obtained with telephones of simpler construction. Phelps therefore constructed the instrument shown in fig. 418, which is known as the Ponny Telephone, and which differs little in reality from Bell's construction.

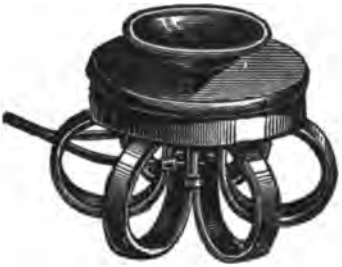


Fig. 417.—Phelps' Crown Telephone.

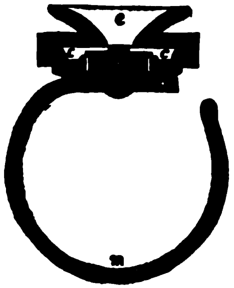


Fig. 418.—Phelps' Ponny Telephone.

We here conclude the description of telephones the effect of which is due to magnetic changes, especially as a comparison of many later inventions with Bell's instrument shows no noteworthy alteration, and certainly no improvement; for although some of the instruments described surpass Bell's instrument in effect, none of them has surpassed or even reached the soft and precise accentuation of it. Here, as in the construction of other machines, new constructions are frequently made simply to obtain new patents, without regard to improvement of effect. The efficiency of a telephone depends less upon the insignificant alterations of a manufacturer, than upon the careful and exact workmanship with which the parts must be fitted.

Working the Telephone.—There is a great difference in the power of different voices to work the telephone. Shouting in it is of no use. The intonation must be clear, and the articulation distinct, and the style of conversation approach more the sing-song. The vowel sounds always come out the best; the palatal sounds *c*, *g*, *j*, *k*, and *q* the worst; in fact the latter sounds are frequently lost. The ear also requires a certain education, and the power of hearing varies surprisingly with different ears and with different people. Singing always comes through with great distinctness.

Other Applications.—No instrument is so delicate as the telephone for the detection of small and sudden currents. It is admirably adapted for showing the currents of induction set up in contiguous coils. If reversals or intermittent currents be sent through one spiral, while the other be gradually removed away, the rapidly diminishing effect of increased distance is very evident; indeed, all the phenomena of magneto-electric inductions are strikingly shown by its means. It enables us to test the resistances of short lengths of wire, and to adjust condensers with great accuracy. Mr. W. H. Preece, of the English Post Office and the Society of Telegraph Engineers, has communicated some interesting results of observations with the telephone, bearing on these points, from which we extract the following:

"The telephone explodes the notion that iron takes time to magnetize and time to demagnetize.* If time were occupied in magnetizing, notes would be changed or lost; but they are not altered. The notion of time is due to the action of induction in coils producing *reaction* and *extra currents*. This is proved by the insertion of an electro-magnet or of coils of wire in a telephonic circuit. While it is possible to speak through a cable 100 miles long laid out straight in the sea, it is impossible to speak through 20 miles when coiled in a tank.

"Its delicacy has detected the presence of currents in wires contiguous to wires conveying currents, which have always been suspected, but have been evident only on wires running side by side for several miles (say 200) on poles or in well-insulated cables. In fact, the most delicate apparatus has hitherto failed to detect the presence of these currents by induction in short underground wires; but the telephone responds to these currents when the wires run parallel for only a few feet. Thus between one floor and another floor, at the General Post Office, it has been impossible to converse by means of the telephone through a wire, owing to the presence of these currents of induction from the innumerable working wires contiguous to it; and through some of the underground pipes of the streets of London sounds are inaudible when the wires are working. In fact, two small-sized gutta-percha'd wires, *one foot long*, were lashed side by side; and when battery currents were sent through one, induction currents were distinctly heard on a telephone fixed on the other. Indeed, this induction between wire and wire has proved the most serious obstacle to the practical introduction of the instrument. But it is not altogether irremediable on underground wires; it can be surmounted in three ways: 1. By increasing the intensity of the transmitted currents so as to overpower the currents of induction, and by reducing the sensitiveness of the receiving apparatus so as to make the instrument insensible to currents of induction, though responsive to telephonic currents. 2. By screening the wire from the influence of induction. 3. By neutralizing the effects of induction.

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* This statement is far too sweeping.—Ed.

"1. Mr. Edison in America has partially succeeded in effecting the first cure.

"2. I have overcome the second difficulty in a way that will now be described. Let 1 (fig. 419) be a wire used for telephonic purposes, and 2 be an ordinary telegraphic wire contiguous to it. Let us regard 1 and 2 as symmetrical and contiguous particles of the two wires. If a current flow through 2 it will affect 1 inductively both statically and magnetically. Let us regard the static effect first. If the current flow away from us, then we may consider the particle 2 as charged positively; lines of electric force will radiate all around it, and that line which passes through 1 will inductively charge that particle *negatively*. This influence being felt all along the wire, a current in the reverse direction to that in 2 will flow through 1. The reverse would occur if we assumed the primary current to flow in the other direction. Hence, an induced current will flow through 1 whenever the current in 2 commences and whenever it ceases. Now, if we place between 1 and 2 a screen of metal, or other conducting matter, in connection with the earth E, then the line of electric force, instead of passing through 1, will terminate at the screen. Hence, if we surround the wire 2 with a covering or sheath of metal, or if we submerge it in water, all effects of static induction will cease between 1 and 2. In water they are not entirely eliminated, for water is a very poor conductor; but they are so reduced by its influence, as my experiments between Manchester and Liverpool and between Dublin and Holyhead have shown, that, if the water or wet serving had been a perfect conductor, they would have been removed as far as regards static induction.

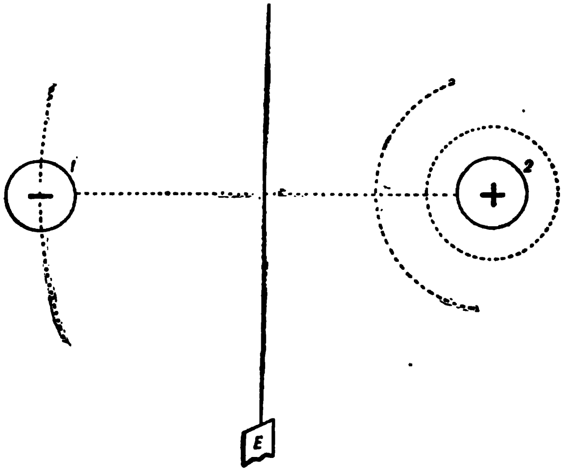


Fig. 419.—Screening the Wire from Induction.

"But we have to regard magnetic induction as well. Besides establishing a field of electric force around 2, a current flowing through that wire establishes a magnetic field around it, whose lines of force are circles, and whose directions are at right angles to the lines of electric force. Let us regard that line of force cutting 1. Each time a current commences, and each time it ceases, in wire 2, a line of magnetic force cuts wire 1, and produces in that wire a current of induction in the same direction as that produced by static induction. Now, if we make the screen of iron, those lines of force terminate in the iron, and wire 1 is freed. Hence, if we sheathe the wire 1 with iron, it is not only freed from the effects of static induction by being surrounded by a conductor in contact with the earth, but it is shielded from the effects of magnetic induction by its sheath of iron. Hence both effects of induction are entirely removed.

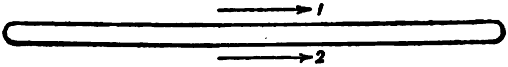


Fig. 420.—Neutralization of Induction.

"3. They can be neutralized by means of a return wire, using this return wire instead of the earth. If 1 and 2 (fig. 420) be two wires running side by side, then the current set up by induction from neighboring wires in one wire is neutralized by the currents set up in the other side.

"But this assumes either that the disturbing wires are at an infinite distance from 1 and 2, or that 1 and 2 are infinitely near each other. All attempts to use return wires on existing poles, in cables, or in underground wires have utterly failed to do away with inductive disturbance; but Mr. Bell has had a single gutta-percha wire carrying two conductors made, which very nearly fulfils the conditions and gives excellent results.

"The extreme delicacy of the instrument has introduced a disturbance from another cause, viz., leakage. Wires on poles are supported by glass, porcelain, and earthenware insulators; but the best support ever devised is but a poor insulator in wet weather. Currents escape over their surface from the wire they support, and these leakage currents find their way into telephonic circuits. Hence a telephone circuit which may work well in dry fine weather, may prove absolutely unworkable in wet weather.

"Another source of trouble arises from what are technically called 'bad earths.' It is almost impossible to make a perfect connection with the earth. There is always some resistance at that point; so that if two wires terminate on the same earth-plate, the one being a working circuit and the other a telephone circuit, some currents from the former are sure to pass through the latter and disturb the telephone. A return wire perfectly cures this evil.

"There are other disturbing elements that are peculiar. Earth-currents, which are always present in the wires, produce a peculiar cracking noise, similar to that produced by a current from a single-fluid battery, such as a Smee or a Leclanché, not unlike the rushing of broken water. This is due to the polarization of the earth-plate, as the sounds produced by a battery current are due to the polarization of the negative plate. When auroras are present these earth-currents become very powerful, and the sounds are much intensified. The effects of thunder-storms are very peculiar: a flash of lightning, even though so distant as to be out of sight, will produce a sound; and if it be near enough to be only sheet lightning, it produces, according to Dr. Channing, of Providence, a sound like the quenching of a drop of melted metal in water, or the sound of a distant rocket. Moreover, he says that this sound is heard before the flash is seen, proving the existence of some inductive effect in the air prior to the actual discharge. The telephone thus becomes an admirable warning of the approach of a thunderstorm.

"Sometimes a peculiar wailing sound is heard, which an imaginative correspondent of mine likened to 'the hungry cry of newly-hatched birds in a nest.' Mr. Preece thinks this is due to the swinging of the wires across the magnetic lines of force of the earth. It is not difficult to conceive that these vibrations may succeed each other in the necessary rhythmic order to produce musical tones. The wires are never free from sound; and every change of temperature or of the electric condition of the atmosphere is recorded on this delicate appatatus.

"The expansion of the iron diaphragm under the influence of the warm and damp breath, when the telephone is first raised to the lips preparatory to talk, is very marked; it produces a faint rustling shiver.

"Immediately on the introduction of the instrument, great anxiety was felt to learn its performance on submarine cables. A telephone was sent to Guernsey, and another to Dartmouth, those two places being connected by a cable sixty miles long. Conversation was carried on, the articulation being perfect, though slightly muffled. This was a surprise; for it was thought that the static induction of a cable, by its retarding influence, would have prevented articulation by lengthening the waves of electricity and rolling them up as it were. I was able to repeat these experiments on an artificial Atlantic cable, constructed to duplex the direct United States cable. There was no difficulty in speaking up to 100 miles, though the muffling effect of induction was evident. Beyond this distance up to 150 miles. muffling commenced to seriously impede conversation, and the sounds diminished considerably in strength: it was like talking through a thick respirator. The effect diminished rapidly up to 200 miles, beyond which articulation became impossible, though singing was distinctly heard; indeed, singing was heard through the whole length of the cable, 3,000 miles long; but this was traced to a secondary cause, it being due to the induction of condenser on condenser. Nevertheless, there is no doubt that singing can be heard through a much greater length than speaking, due to the greater regularity of the successive waves of electricity."

Mr. Preece subsequently experimented on the underground wires between Manchester and Liverpool, a distance of about thirty miles, and through this length had no difficulty whatever in speaking. Again, between Dublin and Holyhead, through the cable sixty-seven miles long, persons spoke with ease, singing coming through with remarkable power and effect. This cable contains seven distinct conductors. When one was used for the telephone, the sounds could be heard on every other wire, but in a feebler degree. When the other wires were working with the ordinary telegraphic apparatus, induction was evident, but not sufficiently intense to stop conversation. Each wire would be surrounded with a wet serving of hemp, but this was not sufficient conducting power to entirely screen the effect of induction. The same effect was experienced between Manchester and Liverpool, where the wires are made up into cables of seven conductors, served outside with tarred hemp.

BATTERY TELEPHONES AND MICROPHONES.

In the preliminary remarks regarding telephony, it has been mentioned that Bell's instrument does good service, both as a sender and a receiver, provided that the sending and receiving stations are not too far from each other. The induced currents generated in the sender are only weak, and are still further weakened by the resistance of a long line, by leakages, etc. To avoid the use of such weak currents, battery telephones or microphones have been constructed (a distinction is sometimes made between a battery telephone and a microphone, but as both are based on the same principle, we shall here treat them together in the same chapter). The suitability of carbon for the construction of such instruments was first observed by Edison, and therefore, without paying attention to the older forms, or first experiments, we shall at once give a description of *Edison's carbon telephone*.

Edison's Carbon Telephone.—A representation of this instrument is shown in fig. 421. The case of the sender consists of metal, and has an ordinary speaking-funnel, opposite to which is placed the membrane D. Behind the membrane is fastened a metal plate, upon which the carbon disc C rests. This disc is held in position by an ebonite ring. The surface of the carbon disc facing the membrane bears a platinum plate P, upon which the glass disc G is glued. This is connected with the membrane by means of the aluminium knob A, so that the vibrations of the membrane can be transmitted to the carbon C, and expose it to a pressure corresponding to the vibrations. A battery current sent through the carbon will therefore be converted into an undulation current owing to the change of pressure. When the plate D presses against the carbon, in consequence of the first or forward phase of its vibrations, the resistance of the carbon becomes less, and therefore the battery current flowing through it becomes stronger. The strength of the current diminishes when the pressure upon the carbon diminishes, by the return or second phase of the vibration of the plate, but a current of a certain fixed strength passes through the carbon when no pressure at all is exerted upon it; that is to say, when the plate or membrane is at rest. The current is conveyed through the carbon by having one of the battery wires connected with the metal case of the telephone, and the other with the platinum plate P.

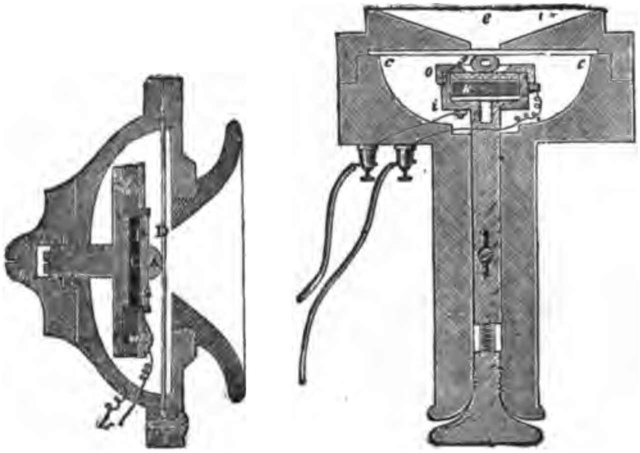


Fig. 421. Fig. 422.
Edison's Carbon Telephones.

Another construction by Edison is shown in fig. 422. The centre disc K is placed between two platinum plates in a kind of box *o i*. The india-rubber tube *g* is placed between the membrane *c c* and ivory disc, which rests upon the upper platinum plate. Each of the platinum plates has a clamp for the wires. The vibrations of the membrane are transmitted by means of the tube and ivory plate to the upper platinum plate, and thence to the carbon. The screw at the end of the case serves to regulate the telephone.

Righi's telephone, which attained a certain reputation in 1878 in Italy, has little originality to recommend it, except its unusually large dimensions. The receiver consists of a Bell instrument, with a straight and very powerful magnet, which has a membrane consisting of parchment, of corresponding size, opposite to it, and carrying in the centre a circular disc of sheet iron. The construction of the sender may be clearly understood with the help of fig. 398, if we imagine the little bar dipping in the fluid to be furnished with a thin metal plate, and a mixture of graphite and silver powder to be substituted for the fluid. The pressure upon the powder will change with the vibrations of the membrane, and the battery current sent through the powder will thus become an undulation current.

Ader, who constructed a receiver similar to the one described, used the apparatus shown in fig. 423, and called it "Ader's electrophone." A wooden frame, which has a handle attached, carries a carbon cylinder *a*, fastened to a wooden pin, at the other end of which is the sound-reflector. The rounded end of the carbon cylinder rests upon the carbon piece *b*, which is connected with one of the clamps, the second clamp being connected with the carbon cylinder itself.

Fig. 424 represents Berliner's microphone or transmitter. The most important portion of the apparatus, viz., the changeable carbon contact, is formed by the two carbon pieces *a* and *b*; the former is fastened in the middle of the thin iron disc, which is attached to the lid of the microphone; the second is placed at *c*, in the catch, which is hung from the movable arm *d*. The contact of the two carbon pieces is brought about by the weight of the carbon piece *b*. The support *d* serves also to maintain the iron disc in its position when the lid is opened. When in use, the poles of this sender p_1 and p_2 are connected with the poles of a battery (usually a Leclanché element); the current then flows from clamp p_1 through the metal piece K to *d* and *c*, and so to the carbon pieces *b* and *a*; thence it returns through the spring f', the screw V, through the primary coil of the induction coil F, thence to the clamp p_2, and so back again to the battery. The clamps p_3 and p_4 hold the wires of the secondary coils, and are connected with the line or earth. If the iron disc is made to vibrate by sound-waves, the two carbon pieces *a* and *b* will also vibrate, causing those alterations of contact which convert the battery current into an undulation current. Every well-acting telephone can be connected with Berliner's microphone as receiver. If the sending and receiving stations are very far from each other, and a considerable resistance in the wires has to be overcome, Berliner makes use of microphones with three contacts.

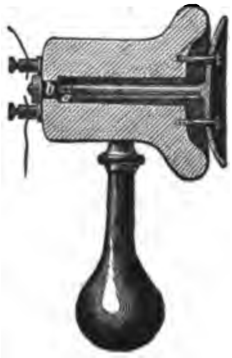


Fig. 423.—Ader's Electrophone.

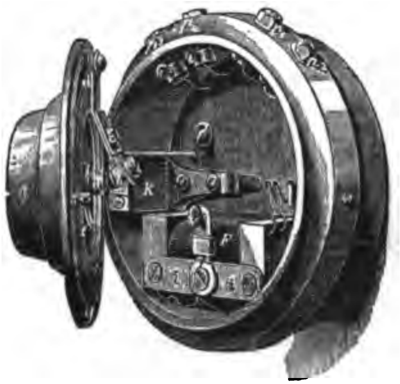


Fig. 424.—Berliner's Microphone.

F. Heller's transmitter, as shown in fig. 425, is a little different from Berliner's transmitter. The lid D of the box has a circular hole in it, in which a disc M M of wood (deal) is placed as membrane; the india-rubber tube *g g* is placed over it, and over this is screwed the brass ring R R in order to hold the whole in position. The carbon cylinder K′ is fastened to the spring F, and the latter is fastened to A. The contact between the carbon cylinder K′ and carbon knob K is regulated by the adjusting screw V. The metal piece A is connected with clamp P_4 by means of a metal strip *a* and a short wire. The carbon knob K is connected with the primary coil of the induction apparatus S by means of the strip *b b*. The second end of this wire is connected with the clamp P_3. The wire ends of the secondary spiral are fastened to the clamps P_1 and P_2. When clamps P_3 and P_4 are connected with the poles of a battery, the current flows from clamp P_4 through *a* A F, the carbon cylinder K′, the carbon knob K, brass strip *b b*, through the primary coil of the induction coil, through clamp P_3, and so back again to the battery. When the membrane M M is made to vibrate, the battery current becomes a primary undulation current, inducing in the secondary coils undulating induced currents, which are conveyed through clamps P_1 and P_2 to the receiving apparatus.

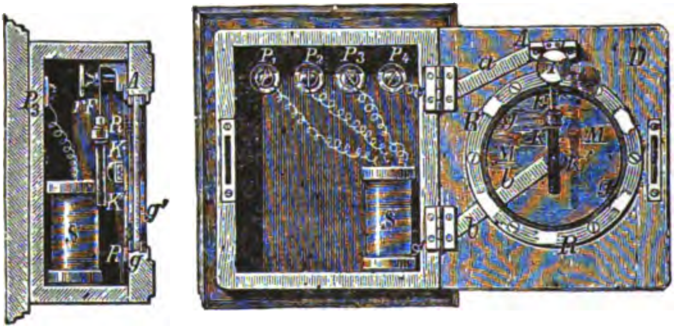


Fig. 425.—Heller's Transmitter.

The microphone by F. Blake differs from others in this respect:—that none of the contact-pieces are fastened to the membrane, and this prevents disturbances due to contraction or expansion of the membrane. The iron sheet M M is placed opposite B (fig. 426), between pads of india-rubber tubing. One of the contact-pieces, consisting of a small platinum cylinder *p*, is fastened to the spring *f*, which presses it against the second contact-piece; a carbon disc (shown in the figure as a black rectangle) is set in the metal piece *m*, and carried by the spring F, which presses both carbon and platinum cylinder against the iron disc. The regulation of the contact is brought about in the following manner:—The spring F is fastened to the plate W, which is again held by the spring F′, which is screwed to the fixed clamp A. The screw S presses against the inclined plane of W,

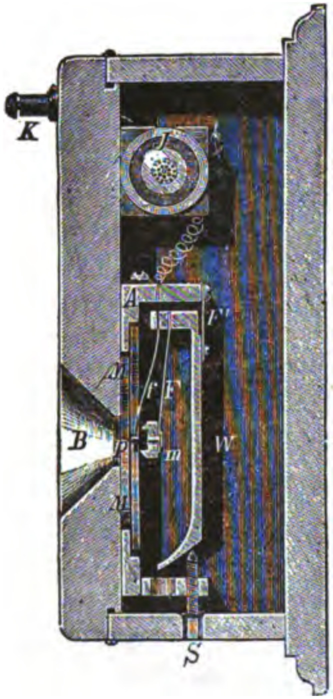


Fig. 426.—Blake's Microphone.

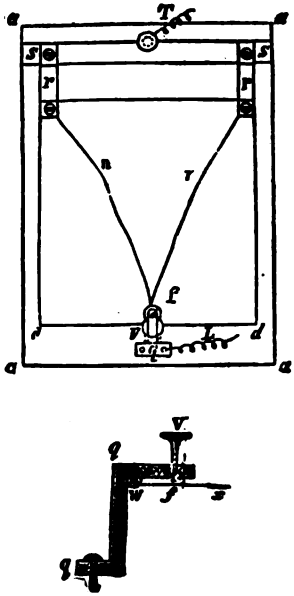


Fig. 427.—Locht-Labye's Pantelophone.

and, by being turned in one or the other direction, effects the regulation. Blake's transmitter is, as a rule, used with a Leclanché element. The current passes as follows:—Through the clamp K into the primary coil of the induction apparatus J, through the spring *f* into the platinum cylinder *p*, through the carbon at *m* into F, through W to S, and then back to the battery.

A very sensitive microphone, called by the inventor a Pantelephone, and shown in fig. 427, was constructed by L. de Locht-Labye. The receiving apparatus reproduces conversations held at a distance of 20 metres from the microphone perfectly distinctly. A plate of either cork, wood, or sheet metal of a rectangular shape, 10 centimetres wide and 15 centimetres long, is suspended from the metal beam S S, which is held by the steel springs *r r;* at its lower edge at *f* it carries a carbon disc, which leans against the silver plate X. This silver plate is fastened to the spring *f*, which is fixed at W. The screw V regulates the contact. The battery current passes through the wire L, *q*, through the spring *f*, and the silver contact, through the wires *n n* and the springs *r r*, and returns through T to the battery. When sound-waves make the plate vibrate the contact becomes changeable, and thus produces undulation currents, which generate undulating induced currents in an induction apparatus, and thus reproduce the sound-waves at the receiving station.

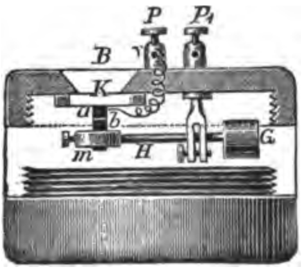


Fig. 428.—Wreden's Phonophore.

The Phonophore, by Wreden, is shown in fig. 428. It consists of a cork plate K, which carries a contact *a*, connected with the clamp P by means of a short wire. The second contact *b* is placed on one end of the lever G H *m*, which has a counterweight at its opposite end. The pressure of the contact between the two pieces *a* and *b* is regulated by the weight G. Wreden constructed microphones also of six and more contacts. The current passes in the microphone shown in the figure as follows:—From the clamp P to the contact-pieces *a* and *b*, through the lever *m* H, and through the clamp P_1 back to the battery.

Microphones with several contacts have been constructed by Crossley, Ader, and Gower. All three make use of a rectangular plate of wood as a membrane. This plate, as a rule, is fastened in the opening of a strong wooden frame, forming with it a box shaped, in Crossley's instrument, like a writing-desk, the inside of which contains the carbon contacts. These consist of four carbon rods, which rest with their ends upon carbon blocks, as shown in fig. 429. The connection of the carbon contacts with the battery is brought about by metal strips, fastened to the carbon blocks. Ader arranges eight or ten carbon rods, as shown in fig. 430, B C D. Ader, who had undertaken the transmission of the opera music to the Palace of Industry during the Exhibition in 1881, placed his microphones upon leaden plates P, in

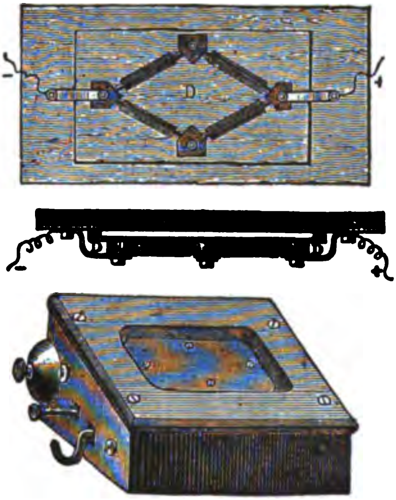


Fig. 429.—Crossley's Transmitter.

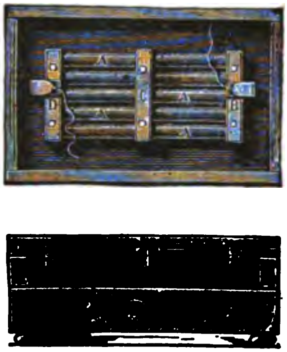


Fig. 430.—Ader's Transmitter.

order to prevent interruption or disturbance of the music transmitted from the voice of the singer by footsteps on the floor, etc. Boudet and others have also constructed microphones of several contacts, some arranged parallel and others in series; the latter arrangement is shown in fig. 431. A glass tube R, of 7.5 centimetres in length and 1 centimetre in diameter, is fastened to a joint upon a stand. The supports T T carry the sounding-tube

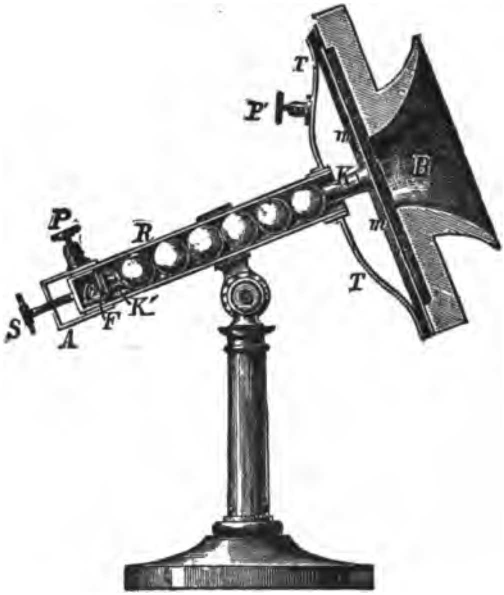


Fig. 431.—Boudet's Microphone.

B, which has on the outer side an ordinary mouthpiece and on the inner side a narrow opening, opposite which is placed the membrane *m m*, made of gutta-percha. The copper-cylinder K, which is connected with the membrane, reaches a short distance into the glass tube, and touches the first of the six carbon balls in it. In the other end of the glass tube is placed the metal piece A, which carries the apparatus for the regulation of the carbon contacts. By turning the screw S in the one or the other direction the cylinder C, along with F and K′, moves forward or backward, thus diminishing or increasing the force of contact between the carbon balls.

Professor Hughes' Explanation of the Action of the Microphone.—Professor Hughes, the inventor of the microphone, has given some interesting particulars respecting the physical action of the instrument. He states the problem he sought to solve by the microphone as follows: To introduce into an electrical circuit an electrical resistance, which resistance shall vary in exact accord with sonorous vibrations, so as to produce an undulatory current of electricity from a constant source, whose wave-length, height, and form shall be an exact representation of the sonorous waves. In the microphone we have an electric conducting material susceptible of being influenced by sonorous vibrations; and thus we have the first step of the problem.

The second step is one of great importance, and was solved by the discovery that when an electric conductor in a divided state, either in the form of powder, filings, or surfaces, is put under a certain slight pressure, far less than that which would produce cohesion, but *more than would allow it to be separated by sonorous vibrations*, the following state of things occurs: The molecules at these surfaces being in a comparatively free state, although electrically joined, do of themselves so arrange their form, their number in contact, or their pressure, that the increase and decrease of the electrical resistance of the circuit is altered in a very remarkable manner, and to an extent that is almost fabulous.

It is only necessary to observe certain general considerations to produce an endless variety, each having a special range of resistance.

The tramp of a fly, or the cry of an insect, requires little range, but great sensitiveness; and two surfaces, therefore, of chosen materials, under a very slight pressure, such as the mere weight of a small superposed conductor (figs. 402 and 403), suffice; but it would be unsuitable for a man's voice, as the vibrations produced by the voice would be too powerful for the instrument, and would, in fact, produce interruption of contact amounting to "make and break."

Pine-wood is the best resonant material we possess, and it preserves its structure and quality when converted into charcoal. A man's voice requires the contact of four surfaces of pine-charcoal. The number of surfaces and the materials have to depend on the range and power of the vibrations, and the surfaces must be pressed together by a force that varies with the force of the sonorous vibrations. Thus, for a man's voice the surface must be under a far greater pressure than for the movements of insects. In order to test whether the pressure is sufficient to admit of a perfect undulatory current being produced by the sonorous vibrations of the range of the voice or sounding body employed, it is well to place a galvanometer in the circuit; while speaking to the microphone transmitter the needle should not be deflected, as the waves of + and — electricity are equal, and are too rapid to disturb the needle. If the pressure on the materials producing the microphonic contacts is not sufficient, we shall have a constant succession of interruptions of contact, and the galvanometer needle will indicate the fact. If the pressure on the materials is gradually increased, the tones will be loud, but wanting in distinctness, while the galvanometer indicates interruptions in the current. By further increasing the pressure the tone becomes clearer, and the needle of the galvanometer will just be stationary when a maximum of loudness and clearness is attained. If the pressure be further increased the sounds become weaker, though they remain clear, and on still gradually augmenting the pressure the sounds die out, until a point arrives at which there is silence.

The simplest form of microphone employed by Professor Hughes in his theoretical investigations consisted of a flat piece of charcoal, 2 millimetres thick and 1 centimetre square, connected with a copper wire, and glued to a board or block of wood. Upon this piece one or more similar pieces were superposed, the upper piece being connected with a wire. The required pressure was put on the blocks. Professor Hughes thus reasons out the nature of the molecular action:

"Let the lower piece be called A, and the upper B; when we subject the board to sonorous vibrations we cannot imagine in the charcoal an undulatory movement of the actual wave-length of the sonorous wave, for that would be several feet; nor can we imagine a wave of any length without admitting that the force must be transmitted from molecule to molecule throughout the entire length. How is it that the molecular action at the surfaces of A and B so vary the conductivity or electrical resistance as to throw it into waves in the exact form of the sonorous vibrations? It cannot be because it throws up the upper portion, making an intermittent current, because the upper portion is fastened to the lower, and the galvanometer does not indicate any interruption of current whatever. It cannot be because the molecules arrange themselves in stratified lines, becoming more or less conductive, as then surfaces would not be required, that is, we should not require discontinuity between the blocks A and B; nor would the upper surface be thrown up if the pressure be removed, as sand is on a vibrating glass. The throwing up of this upper piece B when pressure is removed proves that a blow, pressure, or upheaval of the lower portion takes place: that this takes place there cannot be any doubt, as the surface considered alone (having no depth) could not bodily quit its mass. In fact, there must have been a movement to a certain depth; and I am inclined to believe, from numerous experiments, that the whole block increases and diminishes in size at all points, in the centre as well as the surface, exactly in accordance with the form of the sonorous wave. Confining our attention, however, to points on A and B, how can this increased molecular size or form produce a change in the electrical waves? This may happen in two ways: *first*, by increased pressure on the upper surface, due to its enlargement; or, *second*, the molecules themselves, finding a certain resistance opposed to their upward movement, spread themselves, making innumerable fresh points of contact. Thus an undulatory current would appear to be produced by infinite change in the number of fresh contacts. I am inclined to believe that both actions occur; but the latter seems to me the true explanation; for if the first were alone true, we should have a far greater effect from metal powder, carbon, or some elastic conductor, such as metalized silk, than from gold or other hard unoxidizable matter; but as the best results as regards the human voice were obtained from two surfaces of solid gold, I am inclined to view with more favor the idea that an infinite variety of fresh contacts brought into play by the molecular pressure affords the true explanation. It has the advantage of being supported by the numerous forms of microphone I have constructed, in all of which I can fully trace the effect.

"I have been very much struck by the great mechanical force exerted by this uprising of the molecules under sonorous vibrations. With vibrations from a musical box two feet in length, I found that one ounce of lead was not sufficient on a surface of contact 1 centimetre square to maintain constant contact; and it was only be removing the musical box to a distance of several feet that I was enabled to preserve continuity of current with a moderate pressure. I have spoken to forty microphones at once, and they all seemed to respond with equal force. Of course, there must be a loss of energy in the conversion of molecular vibrations into electrical waves; but it is so small that I have never been able to measure it with the simple appliances at my disposal. I have examined every portion of my room—wood, stone, metal, in fact, all parts—and even a piece of india-rubber: all were in molecular movement whenever I spoke. As yet I have found no such insulator for sound as gutta-percha is for electricity. Caoutchouc seems to be the best; but I have never been able by the use of any amount at my disposal to prevent the microphone reporting all it heard.

"The question of insulation has now become one of necessity, as the microphone has opened to us a world of sounds, of the existence of which we were unaware. If we can insulate the instrument so as to direct its powers on any single object, as on a moving fly, it will be possible to investigate that object undisturbed by the pandemonium of sounds which at present the microphone reveals where we thought complete silence prevailed.

"I have recently made the following curious obervation: a microphone on a resonant board is placed in a battery circuit together with two telephones. When one of these is placed on the resonant board, a continuous sound will emanate from the other. The sound is started by the vibration which is imparted to the board when the telephone is placed on it; this impulse, passing through the microphone, sets both telephone discs in motion; and the instrument on the board, reacting through the microphone, causes a continous sound to be produced, which is permanent so long as the independent current of electricity is maintained through the microphone. It follows that the question of providing a *relay* for the human voice in telephony is thus solved.

"The transmission of sound through the microphone is perfectly duplex; for if two correspondents use microphones as transmitters, and telephones as receivers, each can hear the other, but his own speech is inaudible; and if each sing a different note, no chord is heard. The experiments on the deaf have proved that they can be made to hear the tick of a watch, but not, as yet, human speech distinctly; and my results in this direction point to the conclusion that we only hear ourselves speak through the bones, and not through the ears.

"However simple the microphone may appear at first glance, it has taken me many months of unremitting labor and study to bring it to its present state through the numerous forms, each suitable for a special object."

Professor Hughes, throughout his investigations, used a Bell's telephone as receiver, and admits that it was owing to the discovery of that sensitive instrument that he was able to follow up his researches.

TELEPHONES AND MICROPHONES OF SPECIAL CONSTRUCTION.

The iron wire telephone of Ader is of theoretical interest. Ader tried to construct a telephone without a membrane; for this purpose he used iron cores of different strength. He obtained the best results with very thin iron cores, *i. e.*, iron wires. Fig. 432 shows one of these forms of apparatus; it consists of a board B, through which the iron wire E is pushed and bent at *e*.

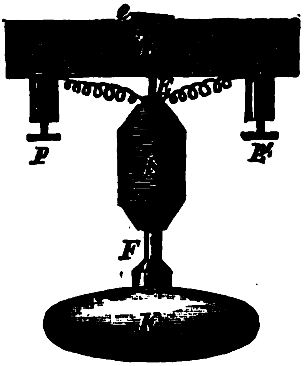


Fig. 432.—Ader's Iron Wire Telephone.

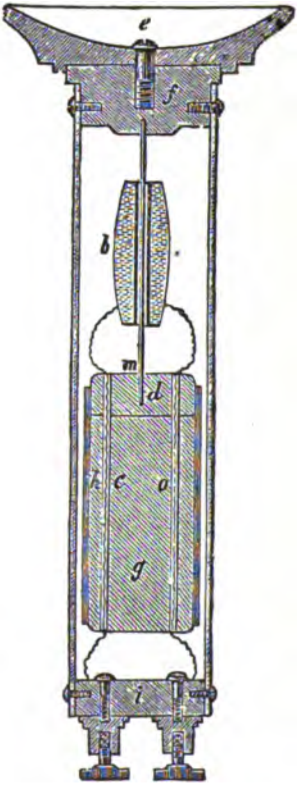


Fig. 433.—Ader's Iron Wire Telephone.

This wire is surrounded by the coil S, which is wound upon a quill F. K is a massive piece of copper, which is soldered to the free piece of the wire. When in use the leading wires of this apparatus are connected with the clamps P P', and the ear is placed at *e*. Words spoken into a distant telephone are clearly heard when the apparatus is 10 or 15 centimetres from the ear. Ader also gave his iron wire telephone the form shown in fig. 433. The iron wire *m* is partly soldered to the massive copper piece *f*, and partly to the copper piece *d*, which again is connected with the copper piece *g*. The upper copper piece closes the upper opening of the tube which encloses the whole apparatus, and is connected with *e* by means of a screw. The sounding tube *e* is similar to that in Bell's telephone, but has no central opening. The copper pieces *d g* form a cylinder, which almost entirely fills the tube, but is separated from the walls by an india-rubber tube placed over it. The insulated wires *c* and *o* are passed through the copper pieces, and form the ends of the induction coil which surrounds the iron wire at *b*. The tube is closed at its lower end by the ebonite disc *i*, to which the two clamps are fastened. The manner of working of the two telephones last described may be explained, according to Th. du Moncel, in the following manner: It has been mentioned that the words reproduced by a Bell telephone are due to the undulation currents which are collected in the receiver, and which cause its iron disc to vibrate in exactly the same manner as the sound-waves cause the iron disc of the sender to vibrate. This explanation, however, is not complete; it still leaves the question unanswered: Of what kind are the vibrations which the iron disc makes? Does the disc vibrate as a whole with transversal vibrations, or do the different iron particles vibrate with molecular vibrations only? Th. du Moncel argues that it is molecular vibration which takes place. Ader constructed the telephones which are described above for the purpose of experimentally determining which of the two opinions is correct. He constructed a telephone without a membrane, that is, a telephone where transversal vibrations cannot take place. As he succeeded in his experiments, he became of Th. du Moncel's opinion, for he proved by them that the reproduction of sound-waves is not *exclusively* due to transversal vibrations. According to Th. du Moncel, the mode of action of Ader's wire telephone is as follows: The undulation currents circulating through the coil *b* cause molecular vibrations in the iron wire. These act chiefly in a longitudinal direction, and spread more quickly than the vibrations of the heavy mass *d g;* the result is that the mechanical effect of the vibrations in the iron wire is greatly increased. The vibrations are then mechanically transmitted to the mass *f*, and spread from there as waves of sound through the sounding-funnel. Ader's iron wire telephone greatly resembles Reis's receiver (fig. 393). The sounding-board is replaced by the copper mass, which takes part in the vibrations and increases their effect.

Fig. 434 represents Breguet's mercury telephone. The two vessels A contain mercury, over which acidulated water is poured, and into which pointed tubes B, nearly filled, are allowed to dip. The mercury in the tubes, as well as in the vessels, is connected by wires, as shown in the figure. The effect of the apparatus is based upon a physical fact discovered by Lippmann when sending currents of electricity through the mercury contained in capillary tubes. Lippmann observed that in every closed circuit electric currents are produced when the surface of the mercury is altered by mechanical means, and conversely that electric currents alter the surface of the mercury. Breguet's telephone is based upon these electric phenomena of capillary attraction. The tubes B B are closed by membranes, which are connected with the mouth-pieces. When sound-waves impinge on the membrane of one part of the apparatus they mechanically affect the mercury, and produce electric currents, which travel to the second capillary tube; these cause a mechanical alteration of the mercury surface, making the membrane of the second apparatus to vibrate in the same manner as the membrane of the first, *i. e.*, the waves of sound of the first apparatus are exactly reproduced in the second

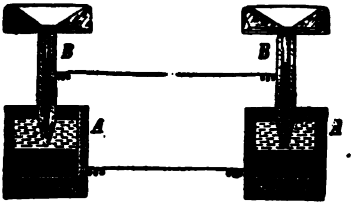


Fig. 434.—Breguet's Mercury Telephone.

apparatus. Breguet's mercury telephone may be used with or without a battery; in the latter case a special arrangement of the mercury and water is necessary.

The chemical telephone by Edison is based upon an electro-chemical phenomenon that has not, as yet, been sufficiently explained; but by using this very phenomenon he constructed, in 1872, the electro-motograph. The phenomenon in question is the following: If a metal plate be connected with the positive pole of a battery, and be covered with paper or any other porous body soaked in potash, and if a platinum or leaden point, connected with the negative pole of the battery, be drawn over the wetted surface, a certain resistance is felt as long as the current is broken, but as soon as the current flows through the metal and the wetted surface this resistance disappears. The current is supposed to react electrolytically on the potash, and cause a thin gas layer between its surface and the pencil, which overcomes the resistance.

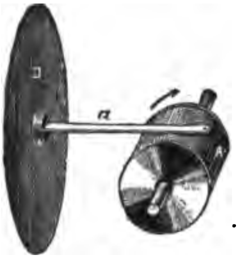
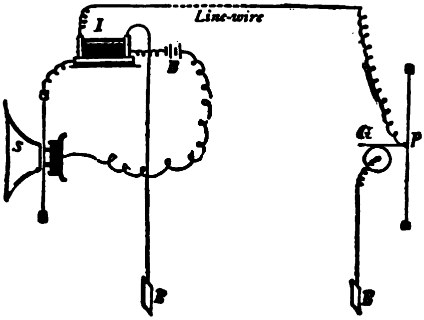


Fig. 435.



Edison's Chemical Telephone. Fig. 436.

Fig. 435 represents the apparatus constructed by Edison on this principle. A metal spring *a* is fastened to the mica disc D, which is of about 10 centimetres' diameter. One end of the spring, which has a platinum contact attached, slides upon a cylinder A, which moves in the direction indicated by the arrow. The surface of the cylinder consists of moist gypsum impregnated with potash and mercuric acetate. The spring *a* is connected with the negative pole of a battery, the cylinder with the positive pole of a battery; some kind of transmitter is also inserted in the circuit. When the circuit is broken the friction between the spring *a* and the cylinder A will cause the former to be taken along with the latter so far as the elasticity of the mica plate D permits. When the circuit is made again the friction ceases, and the disc and spring take up their original position again. When the making and breaking of the current follow each other, or when alterations in the current take place, the resistance between *a* and A will also vary in an oscillating manner, and the mica plate D will therefore begin to vibrate. If the current variations are caused by speaking before the transmitter, the mica plate will reproduce the waves of sound. Fig. 436 shows the arrangement of this chemical telephone system. S represents the carbon transmitter, which, together with the primary coil of the induction coil I, and the battery B, forms a circuit. The secondary spiral is connected on one side with the earth-plate E, and on the other with the spring G fastened upon the mica plate P. The gypsum cylinder, upon which the spring slides, is connected with the earth-plate E.

Dolbear succeeded in the construction of a receiver based on electrostatical principles. This receiver consists in its simplest form of two metal discs of about 5 centimetres' diameter, which are placed parallel and near to each other, but in such a manner as not to touch each other; this is brought about by a frame of gutta-percha, which has grooves for holding the discs, as shown in fig. 437. The gutta-percha fastening is screwed on the one side to a lid, which carries the mouthpiece C, and on the other side to a kind of knob H, which serves as a handle. The screw S is connected with the disc nearest to it, but as this disc is held by the gutta-percha fastening, and at the same time by the screw which passes through its middle, it cannot vibrate. The disc near the mouthpiece is, however, only fastened by its edges, and can be made to vibrate. The screw S not only prevents the first disc from vibrating, but also regulates the distance between the two discs. Each of the metal discs is connected with a clamp A. The clamps also receive the ends of a secondary coil of an induction apparatus, so that the two discs form, so to speak, the poles of an induction apparatus connected with a condenser, in which air represents the insulating layer between the plates. The two discs, therefore, receive opposite electrical charges as soon as induced currents are generated by the induction apparatus. A series of induced currents will cause a series of charges, and as the opposite electrical charges of the two discs cause attraction between them every time they are produced, a series of attractions will be the consequence, *i. e.*, the movable disc will be made to vibrate. These vibrations show themselves sufficiently powerful to be perceptible to the ear. If a sender of any construction be now inserted in the circuit of this apparatus, the induced currents will cause the free disc in Dolbear's apparatus to vibrate, and it will do office as a receiver. The best results were

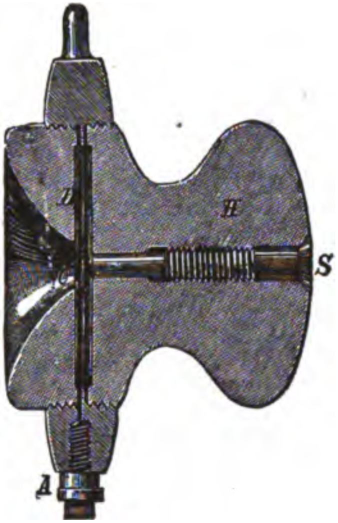


Fig. 437.—Dolbear's Receiver.

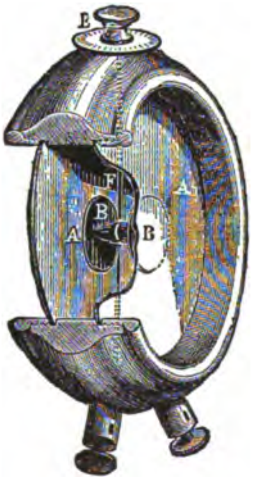


Fig. 438.—Dunand's Torsion Microphone.

obtained by using an induction coil which had a resistance of from 4,000 to 5,000 ohms. The electro-motive force of the induced currents reaches a considerable height, and the usual way of insulating the wires, as in telegraph lines, would not be sufficient. This, however, may be avoided by arranging the induction spiral near the receiver, instead of connecting it with the sender. The comparatively weak primary currents only will then be sent through the leads, and induced currents of high potential generated at the receiving station.

In Dunand's torsion microphone, fig. 438, two thin iron plates A A′ are surrounded by a wooden ring, so as to form a kind of box. Inside this box the carbon contacts, well protected from dust, etc., are placed. The two carbon discs B B are fastened in the middle of the iron discs, and a conical carbon piece of about 12 millimetres in length presses against them. One end of the wire F F, which is wound round the carbon piece, is fastened to the wooden frame, whilst the other end terminates in the knob E. The contacts may be altered by turning this knob, thus altering also the sensibility of the microphone; by having two membranes, two voices may be conveniently transmitted at the same time.

Ader reproduced speech, as already mentioned, by conveying wave-currents through a stretched iron wire connected with larger metal masses. Wildbrant showed that the reproduction succeeded also with wires of other material, when only the wave-currents were sufficiently strong. When Mr. Preece had experimentally convinced himself of the correctness of this fact, he constructed the apparatus shown in fig. 439, on the plan of the thermophone described by F. I. Pisko in his *Telephonie.* This instrument usually consisted of a thin platinum wire stretched between a membrane and an adjusting screw. The wave-currents which are conveyed through the wire produce by their altering strength an undulating heat effect, which manifests itself by the contraction and expansion of the wire that is, by the vibration of the membrane. In the latest form of the thermophone by Preece, a glass tube closed at the end by a cork, as shown to the left of the figure, is employed. Two wires are passed through the cork, and between them is placed a platinum spiral. The undulating currents cause heat-waves in the latter, and, in consequence of this, the wire contracts and expands, and the air in the tube begins to vibrate. Up to the present, however, only feeble results by this action have been obtained.

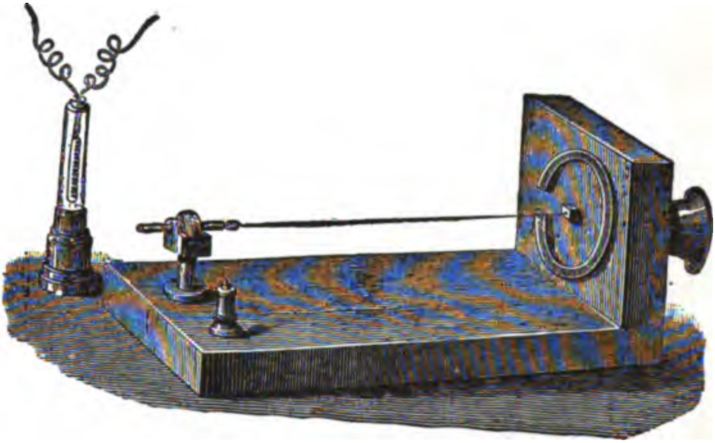


Fig. 439.—The Thermophone.

TELEPHONE INSTALLATIONS.

A. DOUBLE STATIONS.

Fig. 440 shows the arrangement of magneto-electric telephones at the stations A and B. S S′ represent the sending apparatus; H H′ the receiving apparatus; K K′ bells; T T′ keys, and V V′ batteries; E E′ are earth-plates. If A wishes to communicate with B, the key T is first pressed down, and thus a contact is produced at *a*, closing the following circuit: V, *a*, T, through the line to station B, T′, *b′*, lever C′, contact *c′* to the bell K′, from here through contact *d′* to the earth E′ E, and back to battery V. The bell K′ will therefore ring so long as T is held down at station A. The current flows through the bell arrangement in the following manner: First through the coils of the electro-magnet *i'*, then over *h' d'* to the earth. The magnet attracts the armature *m'*, which is fastened to the lever at *h'*, causing it to strike against the bell *g'*. At this moment the circuit is broken because the lever loses contact with *d'*, and therefore the electro-magnet lets go its armature *m*, which swings back into its original position, making contact again at *d'*, when the magnet will again attract the armature, etc. B returns the signal, pressing T' down. By taking down the receiving instruments H and H' from the levers C C', contact is made at *n* and *n'*. Speaking at A generates wave-currents in S, which flow to the contracts *n*, *b*, T, through the line to T', *b'*, C', *n'* and S', to the receiver H', returning again over E' E, and the telephone H, back to S. The wave-currents generated at station B in the telephone S' flow through the same circuit in the reversed direction. When communication is at an end the telephones H H' are put in their places again, thus producing the original joining necessary for signalling. In practice,

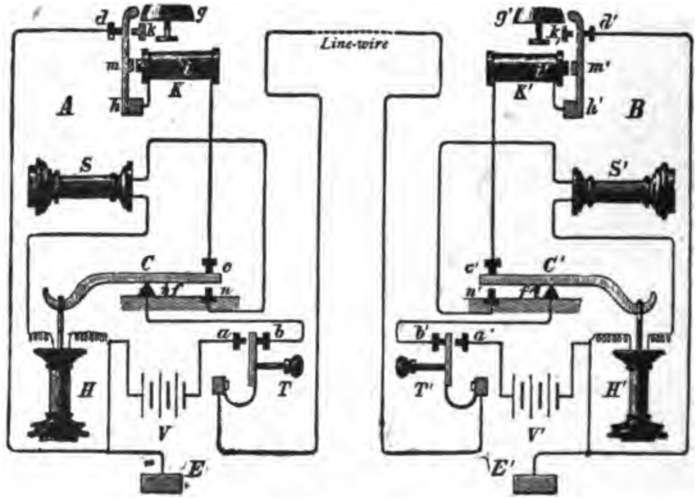


Fig. 440.—Telephone Stations.

however, the same kind of magneto-electric apparatus is seldom used both for receiver and sender, for reasons mentioned already; as a rule, a microphone is used as a sender, and a magneto-electric telephone as receiver. The arrangement shown in fig. 440 is very nearly the same when the telephones are taken off, except that two contacts will have to be made by the levers C C′, as there will now be two wave-currents, viz., the primary and the secondary.

Before we consider the practical execution of the arrangement shown in fig. 440, we must describe some of the separate instruments included in the various circuits. Bells of very simple construction, serving as call apparatus, have recently been constructed by Fein, A. Weinhold, and Abdank-Abakanowicz. The instrument constructed by Weinhold is shown in fig. 441. The iron bell-shade G is screwed on to the upper end of the metal stand A; M is an electro-magnet, having its induction coils at S_1 and S_2; the rounded shoes of these are placed within the bell close to the edge. The induction coils are connected with each other, and also with clamps, to which the line-wires lead by the wires d_1 d_2. One of these clamps is visible at K_1. The wooden hammer K is fastened to the wooden piece V, and pressed against the bell by means of the spring F. If the hammer is allowed to fall upon the bell the latter will vibrate violently, and will cause

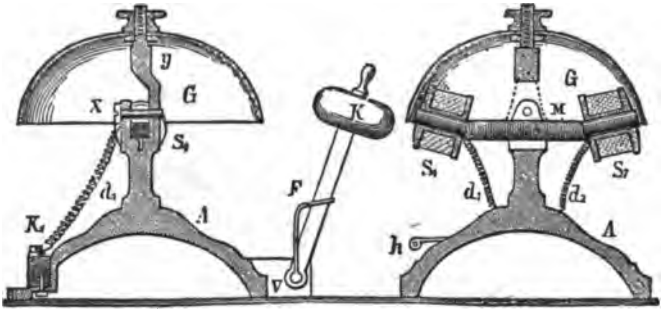


Fig. 441.—Weinhold's Bell.

the bell-edges alternately to approach and be removed from the induction coils and their pole-shoes, thus producing induced currents in the coils. When these currents reach the distant station they cause the telephone membrane to vibrate so violently, that the latter emits a sound, which is still further increased by means of a resonator, shown in fig. 442. This resonator must, however, agree within half a tone with the bell.

The apparatus constructed by Abdank-Abakanowicz is shown in fig. 443. The steel spring C is fastened to the horse-shoe magnet A A. This spring carries the induction coil B with its armatures at its lower end, by means of which the iron core inside the coil is shut off. When at rest the spring C stands parallel to the plane of the magnet-arms and the coil exactly between the two arms. When the coil is made to leave this position by means of D (as shown in the figure), and then suddenly allowed to swing back, it will oscillate between the magnet-poles A A, causing induced currents of alternating direction in the coil; these currents are conveyed either through the spring C and the clamp K, or through the spiral R and the clamp K_1 to the bell of the distant station, which is a so-called polarized bell analogous in construction, as may be seen from the figure, to the inductor apparatus, except that in place of the handle a ball fastened to a rod is used. Two horse-shoe magnets have their poles bent vertically upward, and a flat spring having a coil in its middle portion is fastened between them. When the alternating currents, generated in the induction apparatus, reach the coil, the flat iron spring will swing to the right and left, causing the knob to strike each bell alternately. Experiments have proved that the force

Fig. 442 —The Resonator.

of the currents generated in the induction apparatus is sufficient to ring a bell at a distance of 250 kilometres.

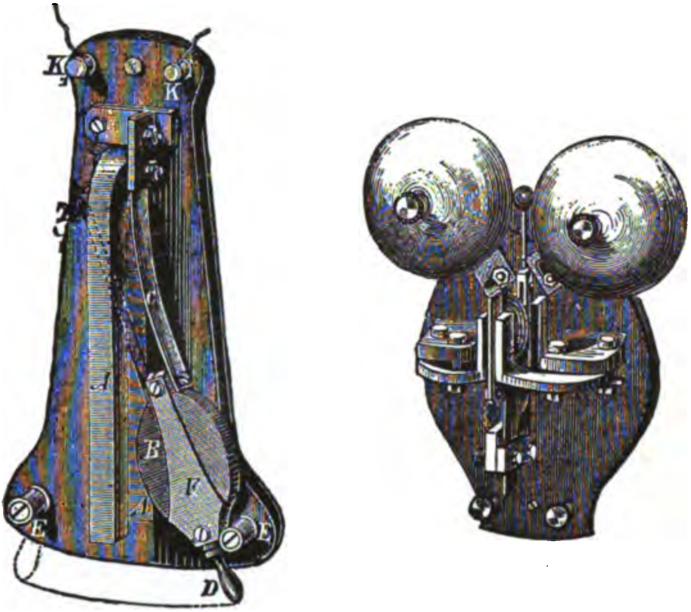


Fig. 443.—Abdank-Abakanowicz' Call Apparatus.

A. Münch took out a patent for a call apparatus which might easily be employed where telephones with horse-shoe magnets are in use. The horse-shoe magnet H H, with its shoes p_1 and p_2, is placed in the telephone frame T T (fig. 444), and the induction coils S_1 S_2 are arranged opposite to the telephone disc E E. The induction coils and the magnet of the telephone are made use of here for signalling. The pole-shoes p_1 p_2 are scooped out semi-cylindrically, and metal plates M M_1 are fastened upon the arms of the horse-shoe magnet H H, which carry two sets of wheel-work *r g h i*. The metal piece *m m* is fastened upon the axis *a* of the spur wheel *r*; *e e* are semi-cylindrical iron pieces, which, with the shoes, form an almost uninterrupted armature (p_1 e p_2), which connects the poles of the horse-shoe magnet H H. This arrangement excludes, so to say, the iron cores of the coils s_1 and s_2, and thus considerably weakens their magnetism. But when the metal piece m m is turned about its axis a through 90°, the iron pieces e e_1 stand at the ends of the horizontal diameter, the armature p_1 e p_2 is interrupted, and the magnetism of the iron cores in the coils s_1 s_2 therefore attains to its original strength. If the metal piece m m be now made to rotate quickly by means of the handle K, the magnet will be opened and closed in quick succession; twice for every full revolution, as arranged in the drawing. The result of this change is that powerful currents are

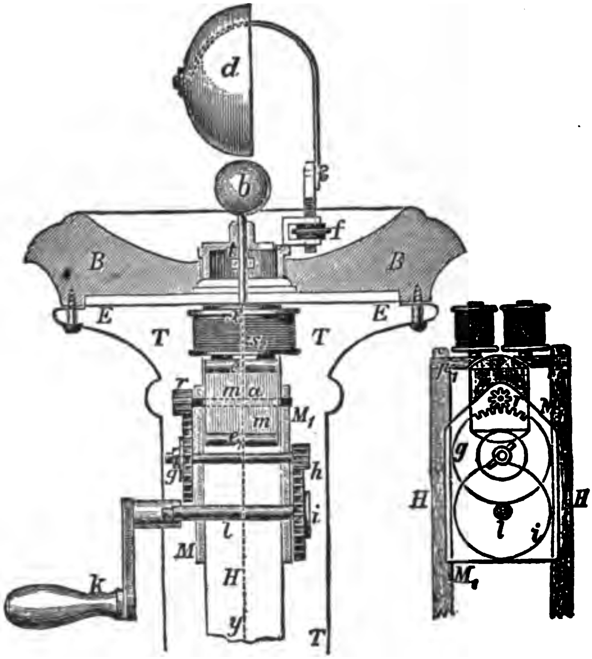


Fig. 444.—Münch's Call Apparatus.

induced in s_1 and s_2. These induced currents reach the telephone at the distant station, making the membrane vibrate audibly. A further increase of tone may be obtained in different ways. Münch, for instance, transmits the vibrations to a bell. For this purpose a small box is placed in the mouthpiece B B, having the rod *t* resting upon the membrane E E, while the ball *b* is fastened upon *t*, and is also connected with this box in such a way that its position can be regulated by the screw *f*. When the membrane begins to vibrate, the motion of the ball up and down causes the bell *d* to ring.

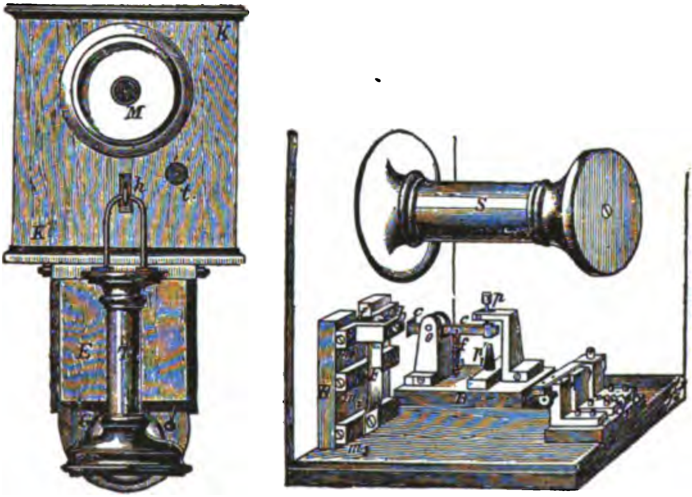


Fig. 445. Fig. 446.
German Speaking and Receiving Instruments.

Telephone Stations.—Returning now to this subject, we shall first consider stations where magneto-electric telephones are used exclusively. Care has to be taken that the several parts of the apparatus are well arranged, and protected from dust, etc. As an example of such an installation, we will first describe a German telephone office, as it is described in Grahwinkel's *Lehrbuch der Telephonie*. Fig. 445 gives an outside view of the whole apparatus; fig. 446, the inside of box K. There are to be seen from outside the receiver T, which hangs on the hook *h*; the mouthpiece M of the sender S; the little box E, which contains the electro-magnet of the call apparatus; the bell *g*, with its hammer, and the key *t*. The remaining portions of the apparatus are enclosed in the box K, which contains, besides the sender S, the contact lever, the contact arrangement belonging to the key, and a lightning-protecting apparatus. The contact arrangement for the alarm consists of the wooden board B, to which are fastened the three brass pieces m_1 m_2 and m_3; m_3 is attached to the metal strip F, which has at its upper end the cylindrical piece t' horizontally arranged, and reaching through the side of the box as key *t*. By pressing upon *t* the cylinder t' is pushed against the contact-plate fastened in *b*, and the current of a battery consisting of from five to six Leclanché elements is sent through the line to the signalling apparatus of the distant station. The contact-lever *c c*, one end of which reaches a hook *h* through the side of the box, moves about the axis *o*; the other end of this lever has two contacts, opposite to which are the contact-piece p_1 on the one side, and the contact-screw *p* on the other. The spiral spring *f* tends to draw the inner end of the lever downward, *i. e.*, tends to make contact at p_1. As long as the telephone L hangs on this hook, the contact at *p* is closed by the lever *c c*; but when T is removed from the hook, the spring *f* draws the lever downward, making contact at p_1, whereby the bell is taken out of the circuit, and connection made between the two telephone stations.

The apparatus for protection against lightning is intended not only to protect the apparatus and locality against currents of atmospheric electricity, but also persons operating or standing near the instrument. The construction of the lightning conductor is shown in detail in fig. 447. The spindle consists of a brass cylinder M. One end of it is screwed into the ebonite piece *e*, the other end is connected with the ebonite piece e_1 by means of a screw; m_1 and m_2 are brass cylinders, forming the end portions of the spindle, which consists of three brass cylinders m_1

M and m_2, insulated from each other. Copper wire of 0.1 millimetre carefully covered with silk is wound round the portions *m* *m*. The wire ends of the coils are led through the grooves *n*, and connect the coils with each other as well as with the two brass cylinders m_1 and m_2 by means of the binding screws s_1 and s_2. The middle portions of the spindle, being covered with wire *d* *d*, do not touch the sides of the hollow space *h* *h* of the brass piece a_1. Care is taken that the contact shall be good between the brass pieces b_1 a_1 c_1, and the brass cylinders m_1 M and m_2. This is brought about by the springs f f_1 f_2 fastened to the screws r r_1 r_2.

The battery currents reach the lightning conductor through b_1, passing through the brass cylinder m_1, then through *s n d n d n s*, into the brass piece c_1 and then to the apparatus (compare fig. 446). If a current of high potential reaches the leads towards b_1 during a thunder-storm for instance, the main portion, instead of flowing through the thin wires *d* *d*, will cross the teeth of b_1 and a_1 (fig. 446), and then flow to the earth. If the branch current entering at *d* *d* is still sufficiently powerful, it will destroy the thin wire of the coil, or at all events its silk insulation, making contact with the piece a_1 leading to earth. When such an apparatus has been destroyed, the spindle is taken out from

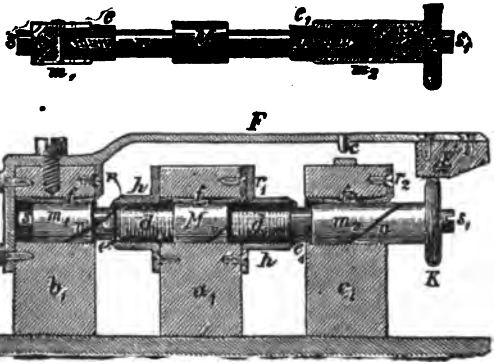


Fig. 447.—Spindle Lightning Protector.

the pieces b_1 a_1 c_1, and replaced by a new one. In order that the line may not be broken during these manipulations, a strong brass spring F, which has a contact at *c*, is screwed to b_1. As long as the spring F is in its place, it presses with its ebonite block E against the knob K of the spindle, and prevents *c* and c_1 from touching. If the spindle is taken out the spring F presses the contact-pin down, and connects b_1 and c_1. The efficiency of this contrivance is shown by the following fact: An unusual heavy thunderstorm passed over Leipzig on the 19th of May, 1884, at which time there were 285 offices established; although only two electro-magnets were damaged, forty-one spindles had to be renewed. A piece of an insulator was broken off, and the wires belonging to it were also torn. The total quantity of electricity which went down a post upon the roof of a house flowed in three different ways to the earth without causing any further damage.

Böttcher's installation of a telephone station with apparatus, specially adapted for the use of mines, is shown in fig. 448. Iron is used in the construction instead of brass wherever this is possible, in order to prevent oxidation. The frames of the receivers, of which there are two at every station, are made of tinned sheet-iron instead of wood. The induction coils are soaked in paraffin, and together with a magnet-inductor, which is used instead of a battery, are enclosed in a box consisting of tinned sheet-iron. The bell apparatus is not connected, but may be placed in position when desired.

Ader's station installation is shown in fig. 449. The several instruments are either enclosed in a desk-shaped box or fastened to it. The lightning-conducting apparatus B is arranged outside, The key T, by means of which the bell at the next station may be rung; the receiving telephone, which hangs on the hook *h* of the contact-lever, and the membrane M, are also placed outside this box. An Ader's microphone is placed inside, which consists of twelve carbon rods K, forming twenty-four contacts with the carbon prisms, which are arranged cross-wise. The induction coil is placed at J. and the contact-lever C is fastened upon a board which is arranged over K. The bell is placed separate from the apparatus, and a battery is used to work it.

Fig. 450 shows an arrangement by De Locht-Labye. A thin cork plate P is placed in the little box to the left. To the lower portion of it is fastened the carbon disc K, against which the contact-pin leans. To the right is placed the electro-magnet W of the alarm, the bell of which, G, is placed outside the box; the disc S is connected with the electro-magnet, and thus an optical signal is given at the same time as the bell signal. The

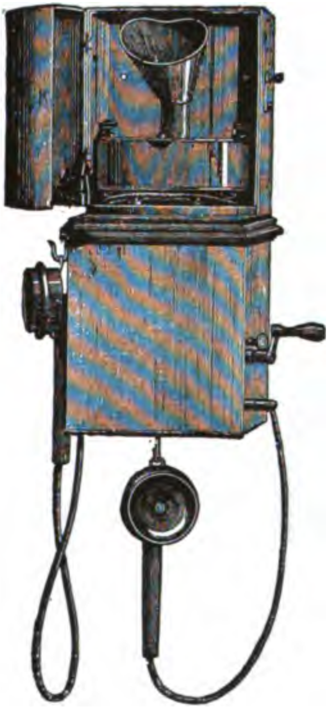
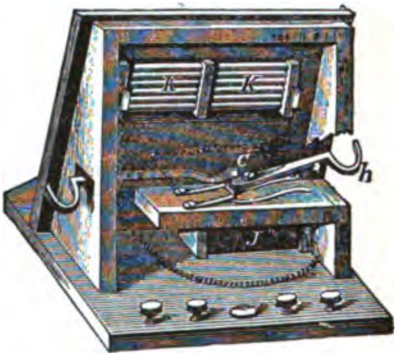


Fig. 448.—Böttcher's Telephone Station.



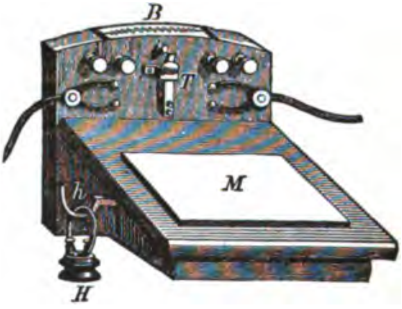


Fig. 449.—Ader's Telephone Station.

receiver, as before, is placed on the hook *h* fastened to the contact-lever C. J is the induction coil, and *t* the key for making contact with the bell battery.

We have only at present considered the arrangement for simple stations; we will next consider the arrangement for central stations. The wires of all the subscribers must terminate at the central station, because each of the subscribers must be able to communicate with the central office, and also with every other subscriber. For this purpose a commutator must be placed at the central station, by means of which the above conditions are fulfilled. This instrument then must consist of an apparatus by means of which every subscriber can indicate that he desires to speak, and further, of an apparatus that enables the different subscribers to communicate with each other. Instruments of

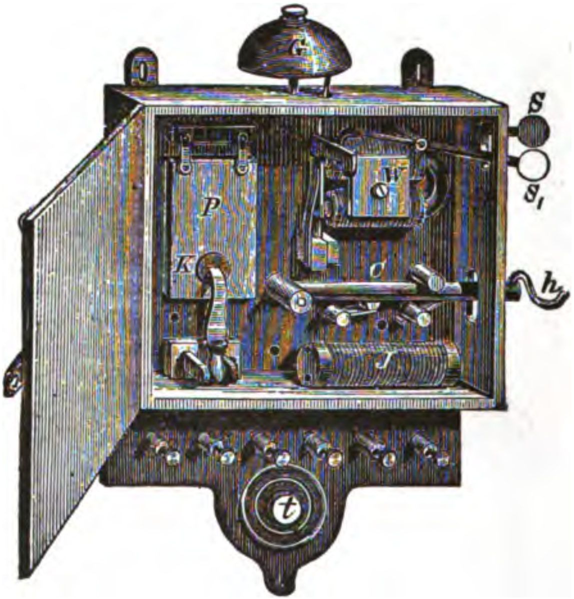


Fig. 450.—De Locht-Labye's Telephone Station.

various forms and constructions are in use, but in principle can be divided into two main types, viz., the Schweizer apparatus and the Jack-knife apparatus.

The principle of the Schweizer apparatus may be seen in fig. 451. Upon a ground frame, usually in the form of a desk, are fastened the metal bars *a b c d* . . . T and E; the well-insulated bars 1 2 3 4 are arranged over these. The bars *a b c d* are called horizontal bars or plates; the bars 1 2 3 . . . are called vertical bars. T is termed the telephone-bar, and E the earth-bar, because T is connected with the speaking apparatus of the central

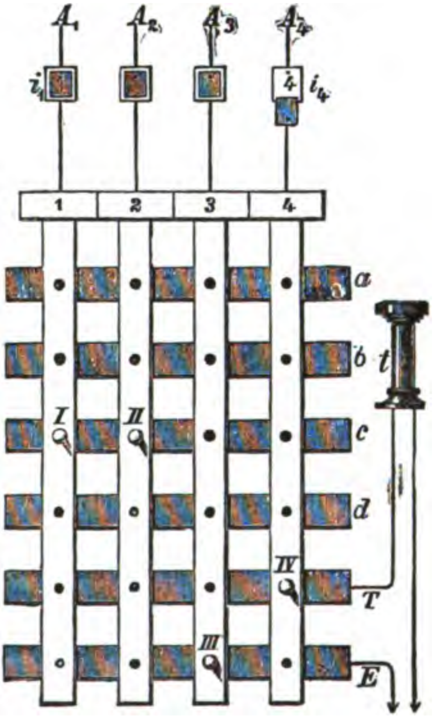


Fig. 451.—Schweizer's Telephone Commutator.

office, and E with the earth-wires. The wires of the subscribers terminate on the vertical bars at 1, 2, 3 . . . having first passed the indicators i_1 . . . i_4. The horizontal bars, when at rest, are single insulated metal strips. The bars may all be connected with each other at their crossings by means of metal plugs. The mode of action of this apparatus is as follows: If none of the subscribers wishes to communicate with another, all the plugs will be inserted in the bars (as seen in the figure, III), *i. e.*, the wires of all the subscribers go through their respective indicators, and then through the vertical bars to the earth-bar E, and so to earth. When one subscriber wishes to communicate with another, he signals with the help of the apparatus to the central station. The slide of this subscriber now falls down at the central station, and allows his number to appear. The officer, seeing that a subscriber (for instance, No. 4) wants to speak, takes the plug out of E and places it at IV. Bar 4 is now connected with the telephone bar, and the subscriber can be questioned about his wishes. Suppose now that it is made known at the central office that A_1 wishes to speak with A_2. The plug of A_1 is taken out of the E bar and placed at I, also the plug at A_2 is taken out of the E bar and placed at II, and in this manner the wires of two subscribers will be connected. Although it does not matter which horizontal bar is chosen, care has to be taken that both plugs are placed in the same horizontal bar without leaving their vertical bars, and that only such horizontal bars are chosen as are not in use already. If, for instance, A_1 is connected with A_2 by having their plugs inserted at I and II, the horizontal bar *c* can no longer be used for connecting A_3 with A_4; either *a*, *b*, or *d* must be chosen.

An instrument constructed on the principle of the Schweizer apparatus by J. Berliner, of Hanover, for twenty-five subscribers, is shown in fig. 452. The commutator is arranged upon a desk-shaped frame placed on the table, and the indicators are arranged in a vertical box placed behind the table. Berliner arranges the horizontal bars above the vertical bars. On the table lies a double plug, by means of which either the call or speaking apparatus of the station may be connected with that of any one who wishes to communicate. To the left of the table are placed the sending and receiving apparatus of the central station. Underneath the table is a box containing the inductor for the bell apparatus, for which a battery may be substituted. In the figure it is assumed that 4 is communicating with 8, 9 with 22, and 16 with 17. The plugs of the remaining subscribers remain in the lowest horizontal bar.

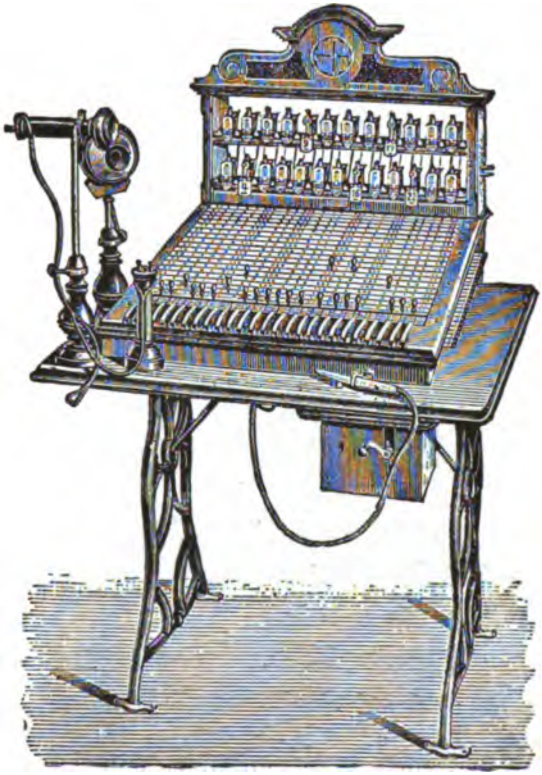


Fig. 452.—Berliner's Central Commutator.

The Jack-knife Apparatus, devised by Wilson ana Haskins, is shown in fig. 453; but the indicator is left out of the figure. The name is derived from the fact that the connections are made by means of plugs resembling the handle of a "jack-knife." The wire, indicated by "Line," connects the subscriber with the central station. The key h_1, which moves about *a*, rests upon h_2, which is connected with the earth; and the subscriber can signal to the central station by pushing in the plug. This plug, or jack-knife, has an insulating handle s, with a collar *r r*, through which the line-wire *l* passes to a metal contact-point *b s*. The collar of the plug fits into a metal socket *m m*, and, when pushed in, the point raises h_1 from h_2, so breaking contact with each, and making contact for the subscriber. The jack-knife apparatus is placed at the central office, with the indicators of all the subscribers arranged in a case, as shown in fig. 454. The lower portion of these cases contain shelves, which serve to hold the batteries B, of Leclanché elements. The upper part of the case G G is divided into five portions by the iron bars *n*, screwed upon

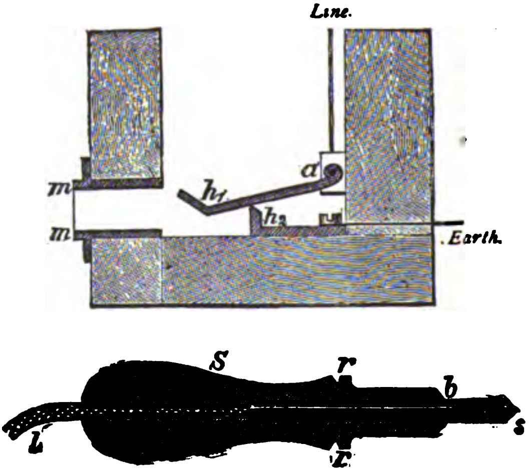


Fig. 453.—The Jack-knife Connection.

the wood; each of the five portions is divided by ten partitions,

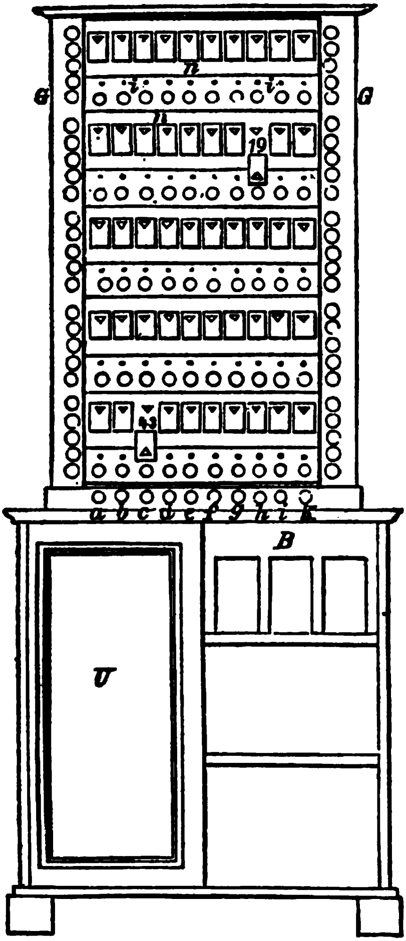


Fig. 454.—Jack-knife Apparatus of Central Station.

so that the whole case has fifty cells or pigeon-holes, each of which contains an electro-magnet. The inside of these partitions is shown in fig. 455. The space between two adjacent iron bars *n* is occupied by the iron plates *p*. These iron plates have painted on them the consecutive numbers, commencing with 1 to the left at the top of the case, and finishing with 50 to the right at the bottom. These numbers are, however, hidden by the covers K when the subscribers are not speaking, but the covers fall down against the pins *i* when the central station is

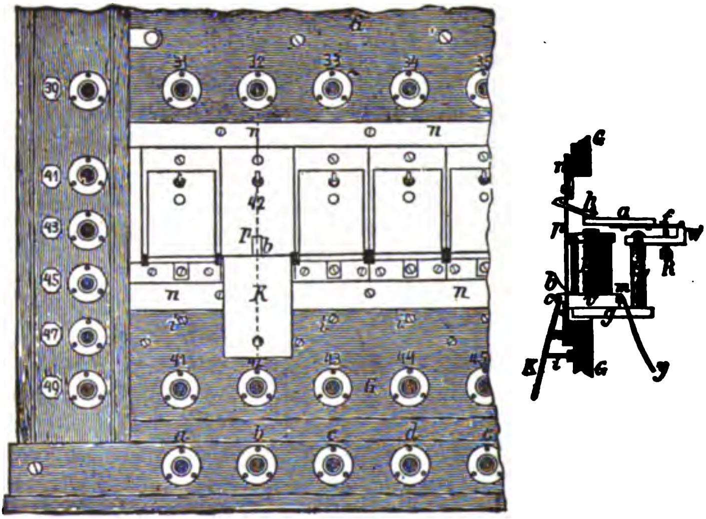


Fig. 455.—Cells of the Apparatus.

communicated with. Underneath each series of covers, holes are arranged which are covered with brass; these have the same numbers as the covers above them, as shown in the figure (fig. 455). There are other and similar holes also arranged along the sides in the vertical bars, each bar having twenty-five. The even numbers are on one side, and the uneven numbers on the other. We shall explain the reason for this arrangement further on. Inside the cell is the horizontal ground-plate *g*, fastened to the lower end of plate *p*; upon this ground-plate and the wooden bar V rests the electro-magnet, of which only the arm E is covered with wire, whilst the core E_1 is left without any coils. The latter carries the brass piece W, to which the spring *f*, with the armature *a* of the electro-magnet, is fastened. The position of the armature can be regulated by means of the screw R. The end of the armature has the hook h_1 fastened to it, which projects through an opening of the plate *p*. The cover K movable about *c*, which covers the number on the plate *p*, has fallen down and rests upon the pin *i*. The cover has also an opening through which the hook *h* passes, and thus it is kept closed when no current flows through the coils of the electro-magnet. The ends of the latter terminate in the insulated brass plate *m*; one end is connected with the wire of the subscriber, and the other with the earth. Whenever a current passes through the coils of the electro-magnet, E attracts its armature *a*, and lowers the hook *h*. The cover K now falls upon the pin *i*, partly by its own weight and partly by the pressure which the small spring *b* exercises, and allows the number upon the plate *p* to be seen; upon this the clerk at the central office connects his apparatus with that of the subscriber. We may here mention that in Germany subscribers use telephones both for senders and receivers; microphones, by Blacke or Berliner, are only used at the central stations.

We have now to consider the arrangement of the twenty-five holes in the vertical bars at both sides of the case. If the plugs were placed in the holes under the covers of the subscribers that wish to correspond, the indicators of both would be inserted, and the resistance in the leads uselessly increased. To prevent this boxes are arranged at the sides of the case, corresponding to those in the middle of the frame, but differing from them by having no indicators behind them, but only jack-knives. Hence for the connection of any two subscribers two kinds of plugs can be used, viz., one by means of which the indicator is inserted, and another which involves no such result; one of the indicators can, therefore, be left out when two subscribers are connected. Suppose A wishes to speak with B. For this purpose

A presses the key *t* of his apparatus in fig. 456, causing the current of his battery, B, to take the following course to the central office: through the wires to clamp A_1, which is fastened to the upper edge of the case at the central station; two ways are now open to it, viz., over *b*, round the electro-magnet E, through K, to the contact *l*, and then to earth; or over *c*, through the spring *f*, and the metal rim of the bore *m m;* but as the metal rim is insulated in the wooden bar G, and the current cannot flow any

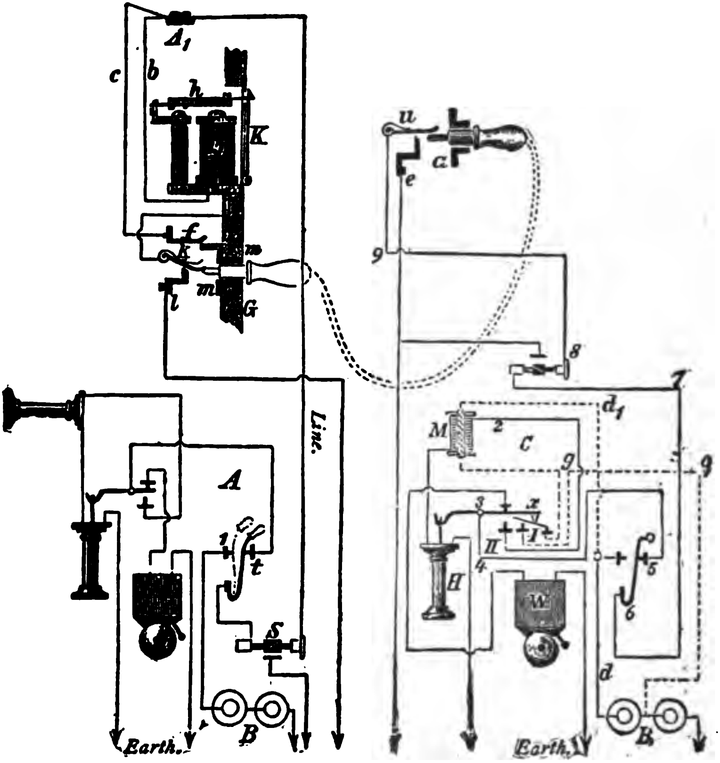


Fig. 456.—Diagram of the Telephone System.

further when the plug is not inserted, the current therefore takes the first direction, that is, over E; consequently the electro-magnet attracts its armature *h*, and causes the cover K to fall down, and to expose the number of the subscriber A, who wishes to speak. The person at the central office now places one of the plugs in the hole *m m* under K (shown by dotted lines in the figure), and the other plug in the hole *a*, as in figs. 456 and 457.

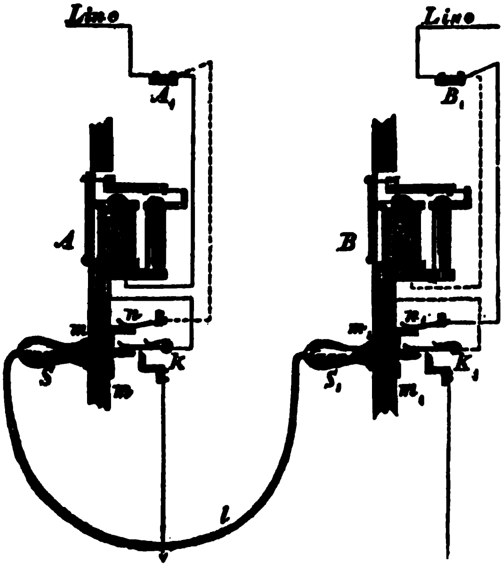


Fig. 457.—Mode of Communicating through the Central Station.

The latch *k* is lifted from *l* and brought into contact with the pin of one of the plugs, whilst the pin of the plug in *a* lifts the latch *u* from the earth-wire *e*, and thus joins the apparatus of the subscriber A with the apparatus C of the central station. The clerk can now communicate with the subscriber as soon as the receiver H has been taken from the lever. When a microphone is used the latter has, as already mentioned, to close two contacts I and II, because two currents are produced, the one primary and the other secondary. For this purpose both contacts I and II are arranged underneath the lever, and a metal spring is pressed upon contact I by turning the lever. The metal spring is connected with the primary wire in the microphone M, by means of the pin X. The other end of the primary wire is connected with the battery B_1. When the lever presses down the spring at X the primary current of the battery B_1 flows from B_1 over d d_1 into the primary coil of M, then through the metal spring to the contact I, and so through g g back to the battery. The secondary currents flow from the secondary coil over 2, contact II, the lever 3 5 6 7 8 and 9, to *u*, which is connected with the apparatus of A. The connection of the subscribers A and B, at the central station, is shown in fig. 457. A_1 and B_1 are the clamps which join their leads. If two insulated plugs S S_1, of a construction like that shown in fig. 453, had been taken, the electro-magnets E E_1 of both subscribers would have been inserted. To avoid this, only one of the plugs S is of the ordinary insulated construction, while S_1 is surrounded by a metal cylinder at the collar *m m*, connected with the point, and so connecting the line-wire with the shunt-contact n_1. In this case the current between A_1 and B_1 is as follows: From A_1 over the electro-magnet E to latch K, and then through the contact-pin of plug S to plug S_1. No current can pass from A_1 through the dotted leads to *n*, because the pin of plug S is only in contact with K. From S_1 two ways are open to the current, viz., through the contact-pin of the plug S_1 over latch K_1, and the electro-magnet E_1 to B_1; and secondly, from the metal fastening of this plug over *m n* to B_1. On the first road the current has to overcome the resistance of the coils of E_1, on the second road hardly any resistance is to be overcome; the current, therefore, takes the road described last, the consequence being that the electro-magnet E_1 is taken out of circuit whilst E remains in it. When A and B have finished their conversation, A again sends a signal to the central station. The officer at the central station takes out both plugs, and establishes the conditions that existed at first. Instruments like those described are constructed by various firms of electrical engineers, with slight modifications in details, the general principle being the same in all.

The "Leads" or Connections of a Telephone System.—In order to obtain a complete picture of the fittings and mode of action of a central station, we shall now have to consider the leads which connect the several stations with the central stations. It is of the utmost importance that the leads should be carefully constructed and well arranged, as the system will not otherwise work in a satisfactory manner. If the main lines are badly arranged, the difficulties of connections will be greatly increased. The main points which ought to be observed when drawing up a plan are as follows: The lines ought to run radially from the central station, and thus facilitate connection with the various houses. The installation ought to be such as to allow of a considerable increase in the extent of the system on all sides; for this purpose main lines should be constructed with treble and multiple poles, because simple poles do not permit any considerable increase of their weight. The crossing of wires must be carefully avoided, because if a wire should break considerable expense and disturbance would be caused by a broken wire falling across others passing longitudinally beneath them. If several telephone offices are erected in the same town, each one ought to have its own district. The supports for leads which are overhead ought to be chosen, placed, or constructed with quite as much care; if roofs are used for this purpose it is necessary to carefully examine their structure. Most people have a strong objection to allow their roofs to be used for these and similar purposes, believing that by doing so the danger of lightning is increased. The opinion is still frequently entertained that the office of a lightning conductor is to draw down the lightning and convey it to the earth, and that the iron matter, without being connected to the earth, would become dangerous. This idea, of course, is entirely erroneous; in reality the effect of a lightning conductor depends upon the point. A positive electric thundercloud, for instance, generates negatively induced electricity in the building over which it may pass. If the tension is sufficiently great, exchange of the two electricities takes place in the form of an electric spark, and thus produces what is called lightning. If the building has a metal point, or a lightning conductor, the negatively induced electricity will flow through it towards the cloud, whilst the positive electricity will flow along the metal down to the earth.

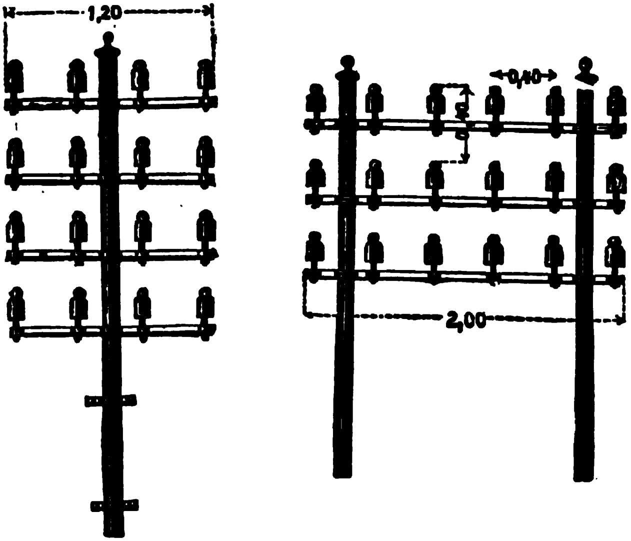


Fig. 458.—Supports for Telephone Leads.

The Wires and their Supports.—The wires generally in use consist of either iron or phosphor-bronze. The posts consist either of iron or wood. The former are composed of wrought-iron tubes of from 6.7 to 7.5 centimetres in outer diameter, and 0.5 centimetre in thickness; arrangements with one and two tubular posts are shown in fig. 458. The mode of fastening the cross-bars Q Q, and the supports S S for the insulators, is shown in fig. 459. The ordinary insulator supports are usually straight, as shown in fig. 459, S S; but if the wire branches off, almost vertically U-shaped insulators have to be used, as shown in fig. 460; moreover, the contact of the wire with the iron posts is more easily avoided by this arrangement. Wood-work is preferable to brick-work for the fixing of iron posts, because in the latter the humming of the wires is far more pronounced. Care ought to be taken, however, that everything is firmly and securely fixed.

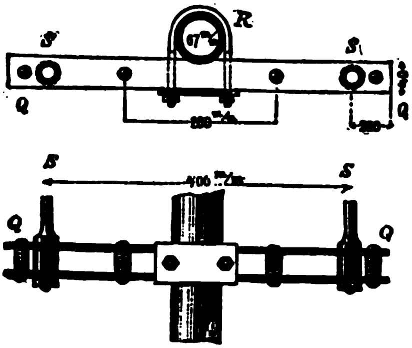


Fig. 459.—Supports for Telephone Leads.

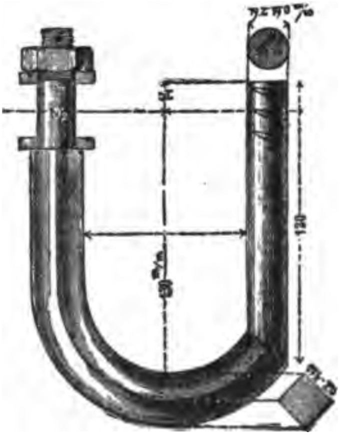


Fig. 460.—Insulator.

The wires are fastened to the insulators in the following way: At each post is placed a man with a line, and the men at the first and last posts have light wooden drums, on which the wire is coiled. Each man throws one end of his line in the direction in which the leads are to be arranged; every two ends are then connected by men placed in the right position for this purpose. This is continued until a continuous line is produced. The wire at the first post is now fastened to the line and drawn over all the different posts. When the first wire has been fastened to the last pole, a second wire is fastened to the line, and drawn by the second line to the first post, and so on. The fastening of the wire to the insulators is shown in fig. 461; zincked iron wire of 2 millimetres' diameter is generally used for the purpose. The so-called top-tie is used for straight lines; side-tie for angular lines. The humming of the wires is often very objectionable; it is caused either by the vibrations of the wires through the wind, or by molecular vibrations, which arise through change of temperature, or perhaps, as Zacharias thinks, by the vibrations of the insulators and wires. Different means have been adopted to prevent the conduction of this humming to the instruments: the tubular posts sometimes, for instance, are not fastened directly to the ground frame, but a layer of lead, 8 centimetres thick, is placed between. The posts themselves are filled with ashes, sand, or similar substances, and are, as we have already said, fastened

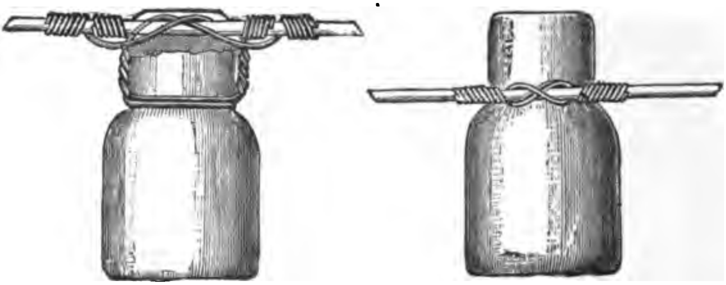


Fig. 461—Top-tie and Side-tie Insulators.

to wood-work instead of brick-work. The German Post-office Department has introduced a manner of fastening the wires, which is shown in fig. 462. An india-rubber tube, the bore of which just fits the wire, is slit open and placed round that portion of the wire which is to be fastened at the pole; a length of about 10 centimetres is generally taken; the india-rubber tube, which faces with its slit to the insulator, is wound round with lead-tape, and the whole bound to the post with ordinary wire. According to Zacharias the humming is almost entirely avoided by winding doubly-covered and well-waxed copper or lead wire round the portions which touch the insulator. A sure, but rather expensive, cure is to have a chain fastened to the wire ends, and connected with the insulators by means of india-rubber.

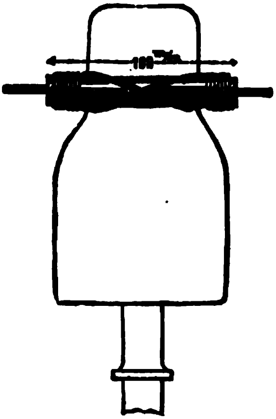


Fig. 462.—Contrivance to Prevent Humming.

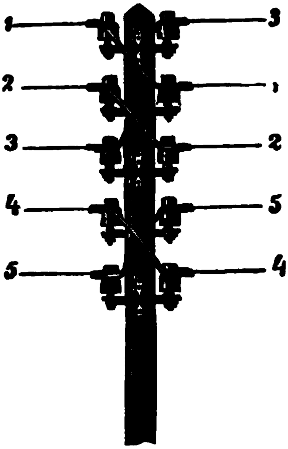


Fig. 463.—Contrivance to Prevent Induction.

Induction.—When two or three telephone wires run parallel to one another, great disturbance is often caused by induction, so that a man stationed at the end of one line can hear all that is said at another. A method of obviating this is to make the conducting wires cross one another at every third or fourth post, as is shown in fig. 463. For this purpose double insulator stages are employed, and the lines are made to end *at the insulators*, as in fig. 463. The cross-wise connection is then established by isolated wires carried round the indicated in the posts, as figure.

It is difficult to decide whether separate lightning conductors ought to be constructed or not; house-owners, over whose roofs the leads run, are often anxious that lightning conductors should be erected; although probably the wires and earth connections are sufficient. Every fourth post is generally converted into a conductor by connecting it by means of a wire rope with the earth. The posts that are not connected with the earth should be connected with those posts that are, by means of wires 4 millimetres thick; and any metal matter, such as cisterns, etc., that happens to be near the building, ought always to be carefully connected with the posts. For the earth connections belonging to the lightning conductors, the Prussian engineering committee suggests that each lead should be provided with a plate, sunk under the lowest water-level; a well can be used for this purpose when it lies outside the building. When no water can be reached, the leads should branch off every 5 metres in veins 3 metres long; earth-plates are not necessary when this is done. Where plates are necessary, copper plates 2 millimetres thick, and having an area of 0.25 square metre in water, and an area of 0.5 square metre in damp earth, are generally employed. When several plates are required for the same building the dimensions may be smaller. The leads to the different subscribers branch off from the main leads, and are conveyed along insulators, which are fastened to the brick-work of the building; in this manner the leads are conveyed as near as possible to the room where the apparatus is placed. A hole is made in the wall underneath the insulator where the lead ends, through which

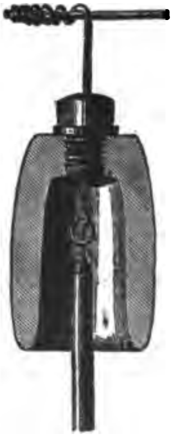


Fig. 464.—Connection of a Branch with the Main Lead.

the tube cable, which connects the outer leads with those inside, is passed.

The joints of branches or stations are protected by means of a gutta-percha cover, shown in fig. 464. Iron wire coated with zinc is let in at the top of the cover, which is perfectly watertight, is wound round the leads in the manner shown in the figure, and then soldered; the end reaching inside terminates in a loop, and the bright copper wire of the cable is connected with the loop. The cover has to stand vertical, and must not touch the cable tube with its edges. The inside leads consists of copper wire 1 millimetre thick, which is covered with cotton, and then soaked in wax. The earth lead consists of copper wire of 1.5 millimetre diameter, which is usually soldered to the gas or water pipes; where this is not possible three wires of 4 millimetres diameter are twisted together, and this cable is connected with the ground-water. Fig. 465 shows the way in which the wires are collected at a central station. A wooden tower is erected on the roof of the building, and the insulators are arranged in rows along the outside. The tower is covered with a projecting sheet-metal roof. It has also a door and platform, which is railed in. Inside the tower the leads are conveyed by cables composed of four tubes, which contain the wires, and which are fastened to the walls of the tower. The cables are free from the tubes at the upper ends, so that the insulated copper wires may be conveyed through the wooden walls singly, and then be connected with the line-wires on the insulators outside the tower. A wooden shaft reaches from the tower to the central station, through which the wires are conveyed to the different cases.

The Telephone System of Paris.—Whilst in most towns the leads used are overhead wires, those in Paris are almost all underground cables. Paris has the advantage of an extensive sewer canal system, and the telephone company was allowed to convey its cables through the different canal tunnels. The cables are fastened by means of iron hooks to the brickwork of the tunnel. Each cable consists of seven double leads (to and fro); that is, of fourteen single conducting wires. Each lead consists of copper wires 0.5 millimetre thick, insulated by gutta-percha from other wires. A cable formed in this manner has a diameter of 2.2 millimetres, inclusive of its gutta-percha cover. Each wire is covered with cotton of a certain color, so that the two wires (the direct and the return wires) of one subscriber show the same color. Seven of such double wires of different colors have tape wound round them, and are then drawn through the tube. A tube cable, containing seven double leads, including the tube

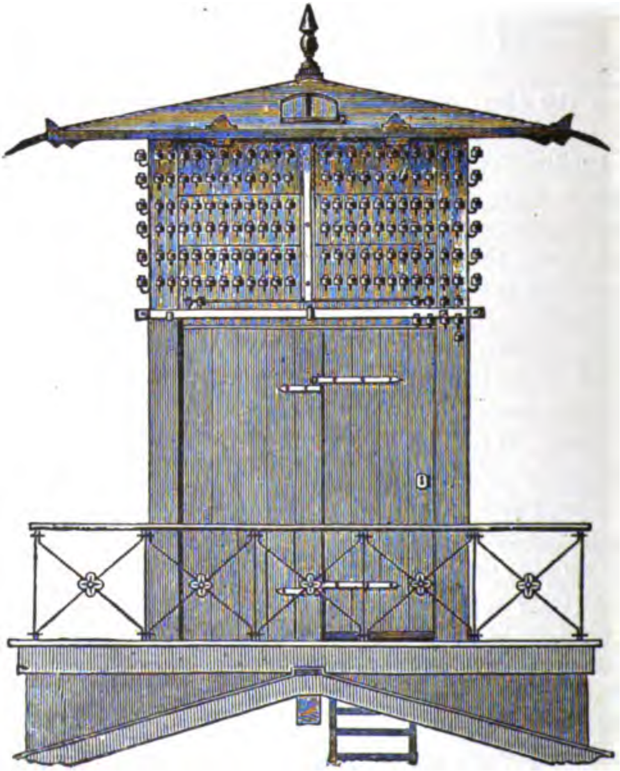


Fig. 465.—The Collector at the Central Station.

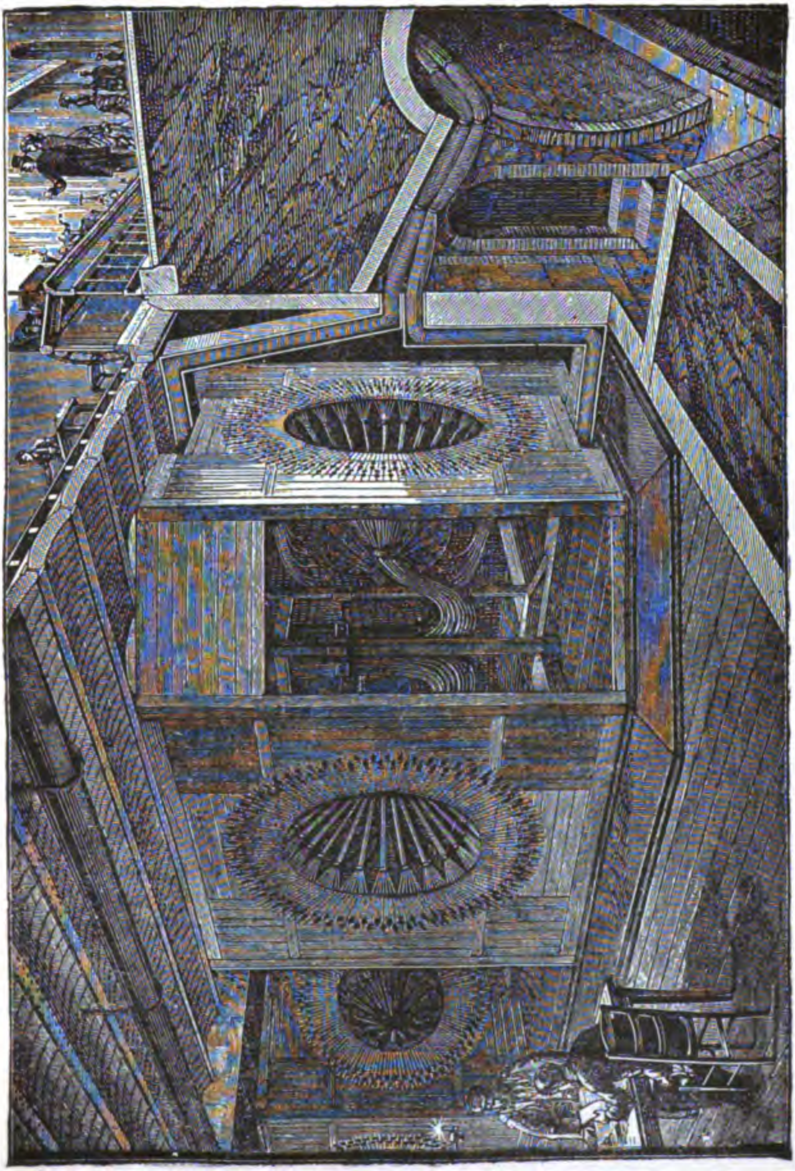


Fig. 466.—The Distribution of the Cables at the Central Station in Paris

and covering, has a diameter of 18 millimetres, whilst a cable with only one double lead (for the connection with only one subscriber) is 8 millimetres thick. The introduction of the leads into the house of a subscriber is very simple. The cable containing the double leads is introduced through the basement, and is then conveyed along one of the walls to the apparatus. Fig. 466 represents the basement of the central station in the Avenue de l'Opéra, where the cables terminate. The door seen in the drawing leads to the entrance of the tunnel. In the basement are arranged eight-sided boxes of wood, the four large

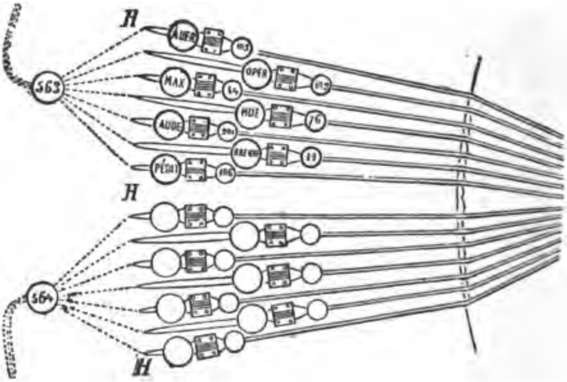


Fig. 467.—The Distribution of the Leads at the Central Station.

faces of which each contain an apparatus for distributing the wires, called, from their appearance, the "roses;" the small faces of the boxes have doors. In the figure one of these doors is left open to make the inside of the box visible. The cables are introduced into these wooden chambers, opened, and separated. The several double wires form large circles with their ends on the outside walls of the chamber, shown in fig. 466, or in detail in fig. 467. By referring to the latter we find that every cable arriving at the inside of the wooden chamber has a number (563 and 564), and that its seven double wires pass through the sides at H H. From here, that is from the periphery of the "roses," the double wires run radially towards the circular opening in the wall of the wooden chamber; they are then again united to form cables, and are conducted in a vertical direction to the commutator at the lower part of the central office. The round discs of the outer circles, fig. 467, consist of bone or ivory, upon which the names of the subscribers are written; the smaller discs bear their numbers.

For very great distances the apparatus and arrangements described above are insufficient; but even when magneto-electric telephones are exclusively used, conversation can take place at a distance of from forty to forty-five kilometres, assuming that the apparatus is in proper condition. The distance may be considerably increased by combining the telephone with a microphone. Experiments made during the Munich Exhibition in 1882, with Bell's telephones and Berliner's and Blake's microphones, showed that communication between Munich and Regensberg (a distance of 137 kilometres) was quite possible. Communication was also possible between Munich and Bayreuth (a distance of 282 kilometres); communication with Dresden, however (450 kilometres distant), was found impracticable.

Herz's System.—Very good results were obtained by Cornelius Herz, who increased the effect of the microphone by increasing the contacts, and putting them in a branch circuit of a powerful battery. He also prevented the induction due to neighboring lines by inserting a condenser in the telephone line, that is, by breaking the line at a certain point. Herz gave different forms to his apparatus, one of which we may describe here. The transmitter consists of the plate *b b*, fig. 468, which moves about the axis *a a*, fastened to the ground-plate M M. The plate *b b* is connected with the membrane *c c* by means of the angular piece *d*, so that the vibrations of the membrane cause the plate *b b* to swing or oscillate. Four pairs of carbon discs k_1 k_2 k_3 k_4 are arranged upon *b b*. The upper four discs are kept in contact with the lower ones by means of leaden weights *g g*. The upper discs to the left are connected on one side with the wires of the battery, and on the other with the upper carbon discs to the right, whilst the lower carbon discs are connected with each other by means of cross-wires. The direction of the current in the transmitter—which is provided with an induction coil, and connected with the telephone T and the condenser C as receiver—is as follows: From the battery B the current reaches the upper carbon plate K_4, then flows through the primary spiral of the inductorium to the lower plate K_3, and then back through the upper plate K_4 to the battery. On account of the connection of the plates

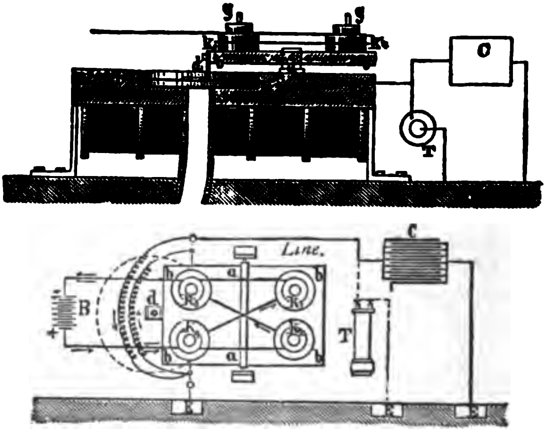


Fig. 468.—Herz's Microphone.

already mentioned, the current from the battery flows also into the upper plate K_4, then into the upper plate at K_2, from here to the lower plate K_3, and then back again to the battery; further, a current flows from the battery into the upper plate K_4 and then to the lower plate K_1, from here it flows to the upper plate K_3, and so back to the battery. These battery currents are converted into undulating currents when the membrane *c c* is spoken against, because the latter communicates its vibrations to the plate *b b*, causing alterations in the carbon contacts K_1 K_2 K_3 K_4. If, for instance, the membrane *c c* vibrates downward, *b b* with its left side will also move downward, whilst its right side will move upward. On account of the great rapidity of this vibration, we may assume that the four upper carbon plates, with their weights *g*, remain stationary, because no time is allowed them to follow the motion of the lower plates. The motion downwards of the left side of *b b* will, therefore, diminish the pressure of the contact in K_3 and K_4, and increase the pressure of the contact between K_1 and K_2. The result of this will be that current impulses of opposite directions will be produced, which immediately follow each other. These impulses, being opposite, would produce neutral effects upon the secondary spiral of the inductorium if their directions were not made to agree by the cross-joining of the alternate carbon contacts. When this is done, the motion of the membrane downward, therefore, produces two impulses of the same nature, the one immediately succeeding the other, and an increase of microphonic effect is the result. The same, only in reversed order, holds good for the motion of the membrane upwards. The secondary coil is connected on one side with the earth, on the other side with the line. A magneto-electric telephone T may be used for the receiving apparatus, as well as a condenser C. The induced currents thus caused by neighboring lines may be neutralized partly by the more powerful effect of the microphone, and partly in consequence of the interruption of the telephone line by a condenser.

The arrangement of a telephone station is shown in fig. 469, but the induction coil is left out in the figure, as it is only inserted when comparatively weak batteries are used. Of the four carbon contacts only two are visible, because the other two are covered. Condensers are used for receivers, in wooden frames of a shape shown in the figure.

Herz with his system spoke between Orléans, Blois, Tours, Poitiers, Angoulême, and Bordeaux—distances of from 300 to 457 kilometres. During the night, when the neighboring wires were at rest, he was even able to communicate between Tours and Brest, over Paris, a distance of 1,100 kilometres.

Connections.—It is of great advantage to connect the telephone offices of two different towns so that each subscriber of the one can communicate with each subscriber of the second. In this case, however, few wires could run parallel to each other for long distances on account of the disturbances which would be caused by induction. By using double lines to connect the telephone offices of the different towns, induction disturbances might be avoided; but the subscriber would also require a double lead for the connection of his apparatus with the office. This is not impossible, as was shown in the Paris installation, but it greatly increases the cost of the telephone network. Systems have therefore been invented which connect the subscribers' single leads to the double leads, and thus connect the central offices of different

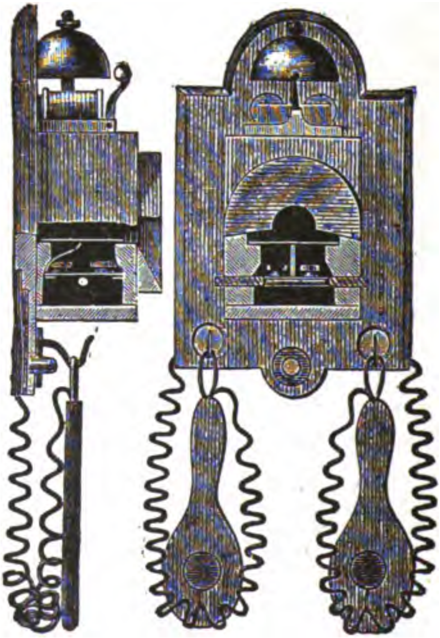


Fig. 469.—Herz's Telephone Station.

towns. Such systems have been devised by Bennett, Ryström, and Elsasser. Ryström's arrangement is shown in fig. 470. The induction coils J_1 J_2 of the two offices to be connected are joined to the leads in the following manner: One end of the primary coil J_1 is joined to the earth leads, the second end to the single telephone leads of the subscriber. The ends of the secondary coil are connected with the line leads 1 3, and, with one coil of the induction apparatus at the second telephone office, form a completely closed circuit. The second coil of the induction coil of this office is again connected on the one hand with the single telephone leads of the subscriber, and on the other with the earth. The undulation currents generated by speaking in the telephone station I produce induced undulating currents in the induction spiral J_1 of this station, which reach the induction coil J_2 of the distant office through the leads 1 3. When these currents arrive they induce undulating currents of a higher order, by means of which the words are reproduced in the telephone II of the subscriber. Although a double change of the undulation currents takes place by this arrangement, experiments made with leads 18 kilometres long, between Malmoe and Lund, gave satisfactory results.

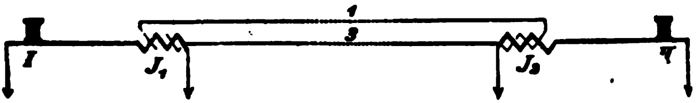


Fig. 470.—Ryström's Arrangement.

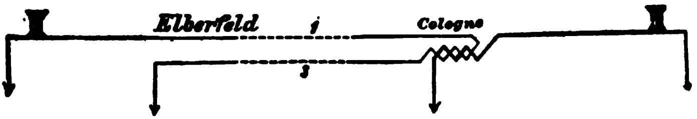


Fig. 471.—Elsasser's Arrangement.

In the arrangement devised by Elsasser, shown in fig. 471, only one induction coil was used, together with a cable of four wires, connecting Cologne with Elberfeld. The telephone apparatus was connected on the one side with the earth, and the other with a cable wire 1; cable wire 3 was connected at Elberfeld with the earth. At Cologne the cable wires 1 and 3 were united by the primary coil of an induction coil. The secondary coil was connected on the one side with the earth, on the other side with a telephone apparatus by means of a single lead. This arrangement requires only a single change of the undulation currents (namely, in the induction coil at Cologne). The arrangement answered its purpose when the wires 1 and 3 of the cable were used—*i. e.*, those wires that lie diametrically opposite to each other. When adjacent wires were taken (1 and 2, for instance), no satisfactory results were obtained. The above arrangements allow communications to pass between the two stations, but signalling through them can only be done by means of very powerful currents.

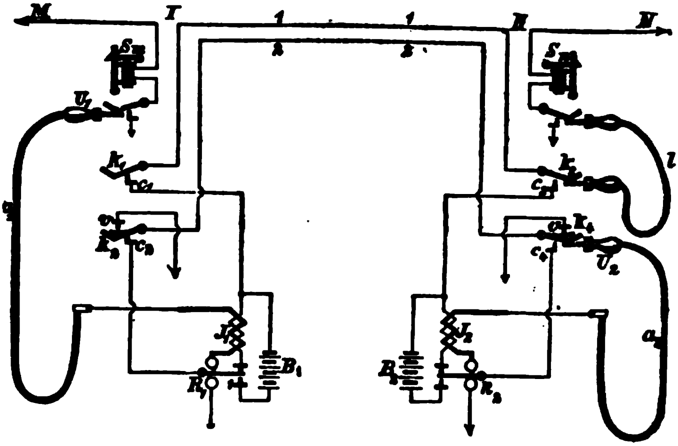


Fig. 472.—Elsasser's Mode of Signalling.

Fig. 472 represents a device by Elsasser, by means of which signals may be sent between the two stations. Besides the ordinary apparatus in the cover case at each station, an induction coil J, a relay R, and a battery B, are needed. The double leads end in the latches k_1 k_2 k_3 k_4; the contacts c_1 and c_3, belonging to these latches, are connected with the induction coils J_1 and J_2; c_2 and c_4 with the relay contacts V V are in contact with the earth. When at rest, the jack-knife plugs U_1 and U_2 of a_1 and a_2 are in the holes belonging to the latches K_2 and K_4 (shown for plug U_2 in the figure). If the subscriber M of the office at town I wishes to speak with subscriber N of the office at town II, he at first sends a current to his office at I, which flows through the magnet S *m*, and then through the latch with its contact to earth, because plug U_1 is not as yet inserted. The armature S *m* of the magnet now falls down, and the attendant at the station I receives the signal of M. M will now be connected with the commutator apparatus and the double line 1 2 by the insertion of the plug U_1 into the latch belonging to S *m*. The office at II is now informed by signal, and inserts plugs in the latch belonging to S *n* and the latch K_3. The current now sent by M flows through S *m* over U_1 a_1, through J J into the relay R_1, and then to earth. The relay closes the contact 1 of the signalling battery B_1, whose current now flows partly over 1, the line 2 2, latch 4, through the spring which touches contact V, to earth; and partly from B_1 over C_1 K_1, through the line-leads 1 1 into the latch K_3, over S *n*, to subscriber N, whose bell it causes to ring. The undulation currents which are generated by the speaking of M take the following route: From M over S *m*, U_1, a_1, through the primary coil of J_1 to the electro-magnet R_1, and so, by means of the relay, to earth. The induced currents generated in the secondary coil of J_1 pass partly over the lever of the relay to C_2 K_2, through the line 2 2, K_4 and V, and then to earth, and partly over C_1 K_1, through the line 1 1 to the latch K_3, and the electro-magnet S *n*, and so into the receiving apparatus of subscriber N, and reaching the earth by that means. The undulating currents generated by the speaking of N take the same direction, only reversed. Both N and M speak through the medium of the induction coil J_1; but signalling can only be effected by M by the help of the more powerful current called into play by the relay. This is no disadvantage, however, for in German telephone offices the rule holds that the person who called shall also give the signal when the conversation is finished. If N wishes to speak with M the conditions are reversed—*i. e.*, the induction coil J_2 only is used, and N alone can give the signal.

Precautions Necessary to Prevent Induction when the Same Line is used for Telegraph and Telephone.—According to Zetsche (*Elektrotechnische Zeitschrift*, vol. iii., p. 244) telegraph lines were used for telephonic messages for the first time in Dresden in 1877, when a line belonging to Government was used both with a Morse apparatus and a telephone apparatus, and the experiments clearly proved that it was possible to use telegraph lines for the double purpose. Franz von Rysselberghe devised a method of using the same wire with a telegraph apparatus and a telephone apparatus, based on the application of so-called "graduated currents." The separation of the telegraph apparatus from the telephone apparatus is brought about by the insertion of condensers. We have already seen that the latter are capable of propagating telephonic impulses, while at the same time they interrupt the circuit of battery currents or induced currents; *i. e.*, the currents used for telegraphing. When telegraphing in the usual manner intermittent currents circulate in the circuit, the currents being made or broken suddenly. These momentary makings and breakings of the current cause powerful induction effects in the neighboring wires, so that telephonic intercourse becomes impossible. These disturbing induction effects disappear, however, when make and break of current is gradual, and not sudden. The current increases gradually when it is made, and diminishes gradually when broken, so that by lengthening their duration the induced currents are weakened to such an extent that they do not interfere with telephonic correspondence. Much more time, however, would be required for sending telegraphic messages by means of graduated currents, and this is evidently the great disadvantage of the system. Rysselberghe converts ordinary currents into gradual currents in a variety of ways, either by inserting electro-magnets or condensers, or by using peculiarly constructed keys. If a battery current has to pass through the coils of an electro-magnet before it sets the telegraph apparatus in motion, it can only attain its full power gradually, because the electric current is employed for some little time in magnetizing the iron core, and it is only when the latter is magnetized that the current will attain its full strength; inversely, on breaking the current its intensity cannot disappear suddenly, because magnetism does not cease all at once. A condenser, too, cannot attain its full charge or lose it immediately when the current is made or broken. The key for the purpose of sending the current gradually has a carbon instead of a metal contact. The gradual change from strong pressure to total break causes a gradual increase and decrease of the current, just as it does in the microphone. The practical execution of these principles is shown in fig. 473. A is the telegraph office, B the telephone office, M represents the key, R a telegraph apparatus of any construction, P the battery, E_1 and E_2 electro-magnets. The former is inserted between P and M, the latter between M and the line L. C represents a condenser put in a branch circuit between the key M and the earth E, in order to connect the two electro-magnets, and c′ represents a condenser that is connected on the one side with the telephone station, on the other side with the telegraph line. The telegraph current coming or passing through the line L cannot reach the telephone T, because the line is separated from the leads of the telephone

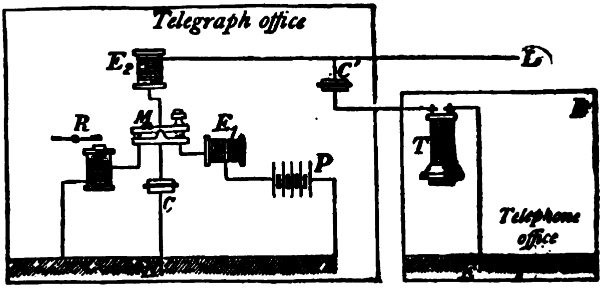


Fig. 473.—Rysselberghe's System.

station by the condenser c′: moreover, the currents of the battery P, which are used for telegraphic messages, are converted into graduated currents by means of the magnets E_1 and E_2. The condenser, as already pointed out, offers no obstacle to the passing of the telephone currents through L.

The connection of two telegraph lines L_1 and L_2 to form one closed telephone line, as arranged by Rysselberghe, is shown in fig. 474. C_1 and C_2 are condensers; B_1 B_2 represent differential coils, which, by induction, affect the third coil B_3; one end of each of these coils is connected with the earth, whilst the remaining end of B_1 is connected with the telegraph line L_1, and the remaining end of B_2 is connected with the telegraph line L_2, and that of B_3 with the telephone line. The connection between L_1 and L_2 is broken for telegraph currents by inserting the condensers. The condensers, however, do not hinder the propagation of telephonic impulses. It will further be seen that the impulses passing through the coil B_3 must have opposite induction effects on the coils B_1 and B_2. They have the relation of + and —as regards each other, and consequently with L_1 L_2 they represent a closed telephonic line.

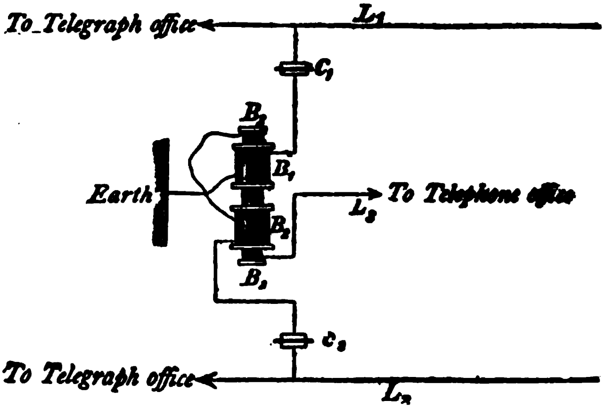


Fig. 474.—Rysselberghe's System.

Experiments were first made with this system in Brussels, in January, 1882; and owing to the favorable results which Rysselberghe has obtained with it, it is intended to utilize the whole of the telegraphic network of Belgium (29,122 kilometres of telegraph wires) for telephonic correspondence.

TELEPHONIC TRANSMISSION OF MUSIC.

The first public experiments were made at the Technical College, Vienna, by F. Nissl, and the author of the present work, in 1877. Bell's telephones were then used both as senders and receivers, but after the microphone had been perfected it was possible to operate on a much larger scale. During the Exhibition of Paris in 1881 the operas and the music of the Théâtre Français could be heard through the telephone in rooms which were specially adapted for the purpose, the installation being undertaken by Ader. The microphones were placed on both sides of the prompter's box in two series, as shown in fig. 475. When arranging microphones for purposes like this great care has to be taken (1) that the music of the orchestra and the singing are equally well transmitted, so that neither the one nor the other is too loud; (2) that the different positions of the singers do not

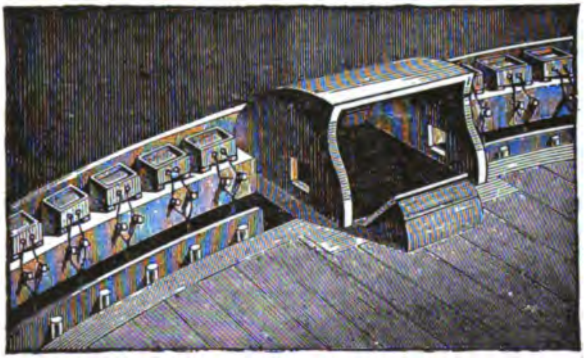


Fig. 475.—Ader's Music Transmitters.

interfere with the effect; and (3) that the microphone does not transmit noises caused by the walking of different people on the stage, etc. The shapes and positions which Ader gave to the mouthpieces of the microphones secured the equal reception of the instrumental music and the singing. To exclude noises the microphones were placed upon thick layers of lead, upon which pieces of gutta-percha had been fixed. The connection of microphone and telephone had moreover to be arranged so that the singers could be heard independently of their position on the stage.

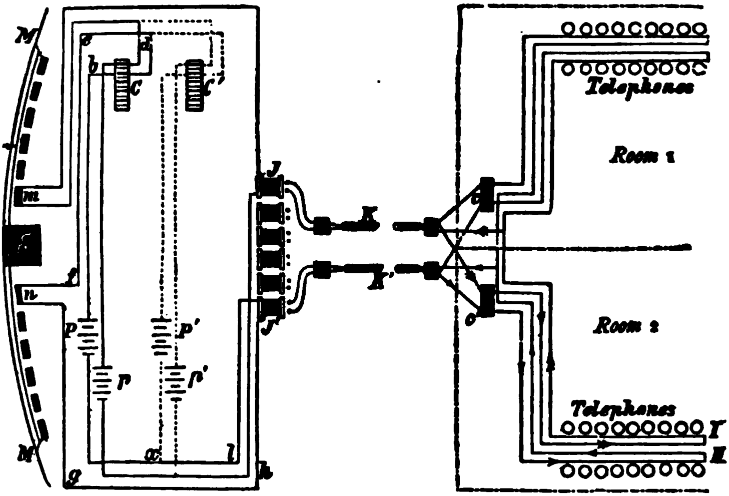


Fig. 476.—Ader's Arrangement of Music Transmitters.

The whole arrangement is shown in fig. 476. According to Th. du Moncel, M M indicate the microphones arranged at both sides of the prompter's box S; P *p* and P′ *p′* are batteries; C C′ commutators, and J J′ induction coils. The leads were conveyed from the opera-house through the cables K K′ to the rooms in the Exhibition building (Palais de l'Industrie), where the receiving telephones were placed. *c c′* are commutators to connect one room, while the public were leaving the other and making room for a new batch of listeners. For the sake of distinctness, the whole direction of current is drawn for two microphones only. To each microphone belong three batteries (of which two only are drawn) and one induction coil. The batteries consisted of Leclanché's elements, which, as we know, do not remain constant very long; the elements had, therefore, to be charged frequently, which was effected by the arrangement of three batteries and a commutator belonging to each set. The direction of the current for the microphone *n* is as follows: From P over *b* through the commutator *c*, to *d e f* through the microphone *n*, over *g h* through the primary spiral of the induction coil J′ and over *l* back to the battery P. If P loses its constancy, P′ takes its place, and the direction of the current is as follows: From P′ through the commutator *c*′, then over *d e f n g h* J′ *l* to *x* and back to P′. The battery *p* or *p*′ furnishes the current for the microphone *m*, in the circuit of which the induction coil J is inserted. The arrangement, as described above, allows a uniform reception of the waves of sound by the microphones, independent of the duration of the performance and the position of the singers. The reproduction of these waves in the different telephones of the listeners is brought about by the peculiar mode in which the telephones are joined with the secondary coils of the induction coils. The ends of each secondary coil, as for instance of J′, are connected with the corresponding cable K′, which leads from the opera-house to the listeners'-room. One of the ends of the induction coil is connected with the commutator C as well as with *c*′, and the other end is simply joined to the leads leading to the telephone. If, for instance, connection of the cable is made with room 2 by means of the commutator *c*′, the undulating induced currents from the coil J′ reach the series of telephones indicated by II, and pass through their circuit in the direction indicated by the arrows. The currents from the coil J reach the telephone line I, and pass through it in the direction of the doubly-barbed arrows. As J_1 is induced by the undulating currents of the microphone *n*, and J by those of the microphone *m*, if each listener receive a telephone of row I, and also one of row II, he will be able to hear equally well whether the singer is to the right or to the left of the prompter's box, or if opposite to it. All the microphones being connected in this manner with the telephone couples, this holds good for each listener.

Fig. 477 shows the connection of the Royal Opera with the Rotunda of the Exhibition building during the Exhibition of Vienna, 1883. This telephonic transmission of music was undertaken by the Private Telegraph Company after the plans of their engineer, A. Kittel. M M represents the microphones, B B their batteries, J J the induction coils, H R O the telephones. The twelve microphones placed at the opera-house were divided in two groups, each group consisting of six, or of three couples of microphones, joined parallel, so that each couple consisted of a microphone placed at the right side of the stage and a microphone placed at the left side. Only eight microphones are drawn in the figure, forming two groups of two couples. To maintain the current for the microphones and the induction coils constant, commutators S S are inserted into the primary circuit, so as to allow of the insertion of a fresh battery in the place of the exhausted battery.

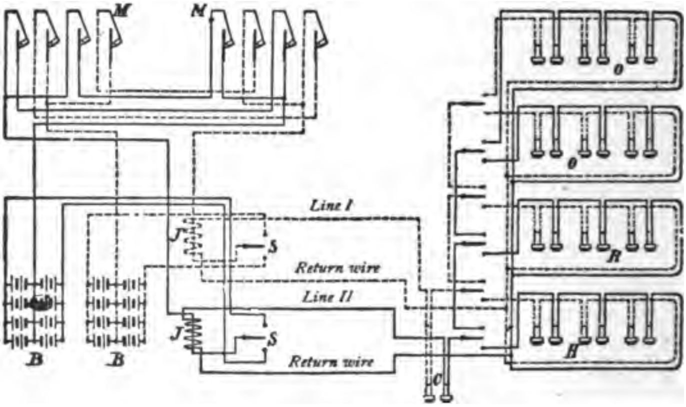


Fig. 477.—The Telephonic Transmisson of Music at Vienna.

The leads from the Rotunda terminated at the office where the control telephone C and the apparatus for the office correspondence were placed. Each of the cells O O contained sixteen telephone couples for the transmission of the opera music. The cell R contained thirty telephone couples for the transmission of the music from the Vienna Rollschuh Club (distance three and a half kilometres). H was a box containing seven telephone couples, reserved for visitors. In each auditorium the telephones of one circuit were joined in series, and every telephone couple contained a telephone of each of the two circuits.

SPECIAL APPLICATIONS OF THE TELEPHONE AND MICROPHONE.

Police Use of the Telephone.—The telephone plays an important part in the police system at Chicago. Each policeman is in a position to communicate at once or within a few minutes with his own or the central station; trustworthy citizens are also in a position to call for help; and as thieves, as a rule, know when and where policemen are present, and arrange their plans accordingly, and policemen are seldom where they are wanted, such an arrangement is of great value. At certain points of each district police stations are erected, where there are three men, one horse, and a wagon always ready; and these stations are put into telephonic connection with alarm stations, which are similar in form to sentry-boxes. These boxes, which are just large enough to admit one person, are placed in the different streets at certain intervals, and can be opened by means of keys in the possession of policemen and respectable inhabitants of the town. To prevent misuse the keys are numbered, and once placed in the lock, can only be removed by the police. The box contains a pointer apparatus and a locked case, which can only be opened by the policeman, and in which the telephone apparatus is kept. The pointer apparatus, which is shown in Fig. 478, is capable of sending eleven different signals; police wagon, thieves, forgers, riot, drunkard, murder, accident, violation of city property, fighting, test of line, fire. The one who gives the signal has

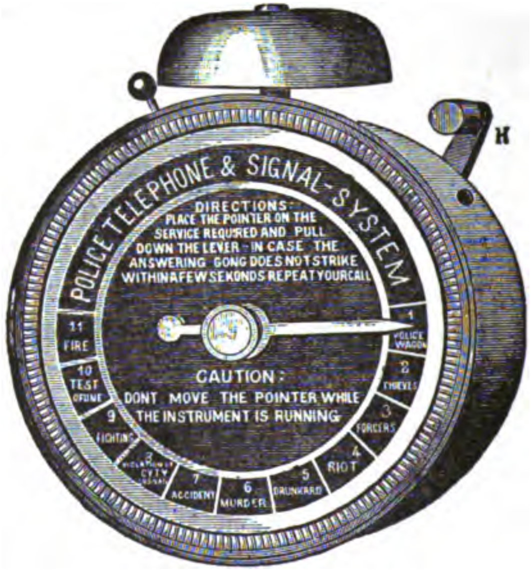

POLICE TELEPHONE & SIGNAL-SYSTEM
DIRECTIONS:
PLACE THE POINTER ON THE SERVICE REQUIRED AND PULL DOWN THE LEVER - IN CASE THE ANSWERING GONG DOES NOT STRIKE WITHINAFEWSEKONDS REPEATYOURCALL
CAUTION:
DONT MOVE THE POINTER WHILE THE INSTRUMENT IS RUNNING
1 POLICE WAGON
2 THIEVES
3 FORGERS
4 RIOT
5 DRUNKARD
6 MURDER
7 ACCIDENT
8 CITY
9 FIGHTING
10 TEST
11 FIRE
H

Fig. 478.—Chicago Police Signal.

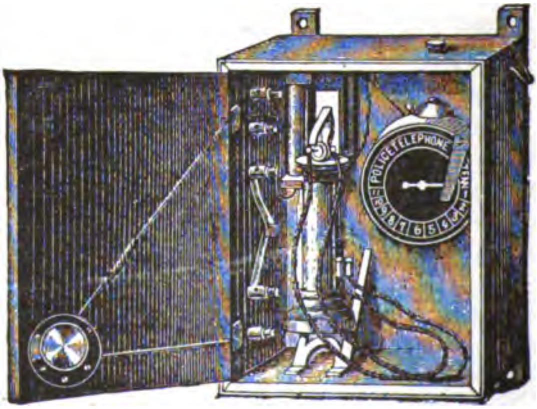


Fig. 479.—Chicago Police Telephone.

only to place the pointer and press down the lever H. The receiving apparatus at the police station consists of an ordinary Morse apparatus. Fig. 479 shows the apparatus contained in the locked case. It contains a telephone and microphone, and allows the policeman to communicate with his station, and the inspector making the round to send his reports at certain intervals through the telephone to his superior. At the request of townspeople the alarm apparatus may be erected for them at their houses or places of business; but, in these cases, the door-key, placed in a sealed envelope, is deposited at the police station, so that the policeman may enter the house of the person calling for help.

Military Use of the Telephone.—As the telephone, compared with the telegraph apparatus, requires no specially trained men for the purpose, it is used with advantage for certain military purposes. In the practice of troops over a large area, orders can be communicated by telephone; for instance, to give the infantry opportunity to practise firing, movable targets are fired at with cartridges, and have to appear and disappear in different places at certain intervals. The officer in command must have a perfect control over these targets, and must be able to communicate with the persons that have to move them. Lieutenant Laffert reports that telephones are well adapted for this purpose. Siemens' telephones are generally used in these cases, and are connected by a cable, which consists of two copper wires of 0.8 millimetre, wound in lengths of 500 metres upon a portable roller, as shown in fig. 480. The sheet-metal cylinder *a a*, which is 10 centimetres long, has two discs of hard wood *b b* fastened upon it; the disc *d* divides the cylinder into two halves *e e*, each of which contains a telephone; *f* is an opening in the sheet-metal cylinder, sufficiently large to allow the cable to come through. On the outside of the wooden disc nearest this opening the clamp *p* is fastened. The beginning of the cable is connected with the clamps of the telephone, the end with the clamp *p*. Straps are fastened to g_1 g_2, so that one man can conveniently carry the whole apparatus. When the apparatus is to be used, the portion *e*, which has not had its telephone connected with the cable, is taken out; the cable end is then removed from the screw *p*, and connected with the free telephone; two men take hold then of the handles *l m*, and walk quickly towards the place appointed.

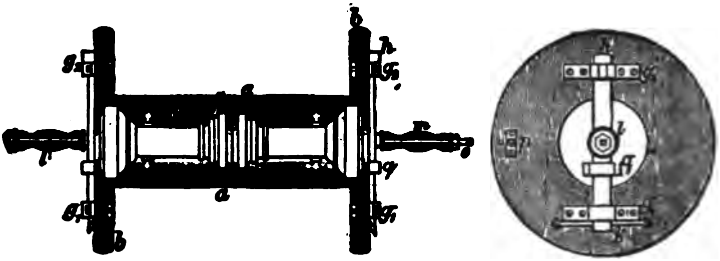


Fig. 480.—Portable Telephone Systems.

In order to somewhat lighten the out-post service of troops enclosed in fortified places, A. Axt proposed the use of telephones combined with microphones. Suppose, for instance, the point A (fig. 481) has to be guarded through a distance of 4,000

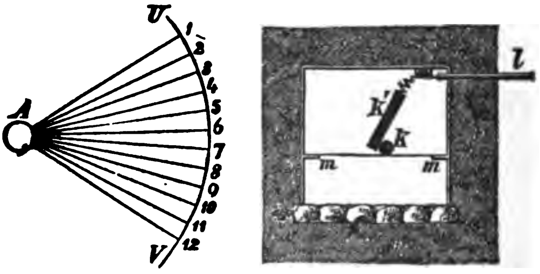


Fig. 481.—Military Microphone.

metres, along the arc U V of 65°. Microphones are sunk about one metre into the earth, at distances of 400 metres from each other, and the different leads are conveyed underground to the point A, where they are connected with a telephone. The microphones, which are constructed as shown in the right-hand figure (481), consist of cubes of tinned sheet-iron of 3 millimetres thickness, open at one side. The metal membrane *m m* is arranged as in telephones. On the upper surface of the membrane a small carbon cylinder K is fastened, and against this a second carbon cylinder K′ is made to lean at an angle of about 80°. In order to make the contact of the carbons easily variable, the carbon K′ is hung from the line-wire *l* by means of a spiral spring. The leads of all the microphones are conveyed to the point A, where they are connected with the bars 1 to 12 of the commutator (fig. 482). The second layer of bars is connected with the telephone T, the battery B, and a galvanometer G; one of the bars is also connected with an earth-plate E. It will now be an easy matter to trace the courses of the current when the connections are made by inserting the plugs in the proper places for the communication it is desired to secure. Suppose, for instance, that the bar 1 is plugged with *a* and *b* and the earth-leads, the current flows either from the battery through the galvanometer and the telephone to bar *a*, and so to the earth, or else from the battery through the bar *a* into the leads 1, into the microphone connected with 1, through its carbon cylinder K and metal mass into the earth. It will not be difficult to distinguish, by means of the telephone, whether single persons or troops, cavalry or artillery, are approaching the respective microphones.

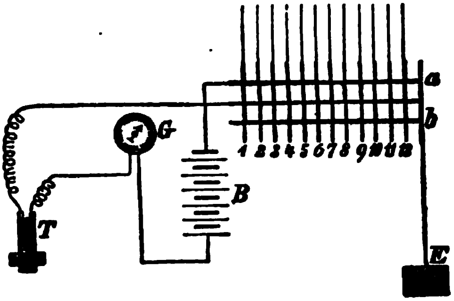


Fig. 482.—Commutator.

Instead of one telephone, several may be joined to the commutator.

Divers' Telephones.—Fig. 483 represents a telephone specially devised by Captain Des Portes for divers. The telephone, which may be used both as receiving and sending apparatus, has the form of a round box B, in which a bent magnet is placed. The box is fastened to the plate *a b*, which is fixed inside the helmet. From the one clamp the wire leads to the helmet, which serves as earthplate, whilst the wire from the other clamp S connects it with the cable K of the ship. The wire from S passes through the plate *a b*, and then through a gutta-percha plate *c*; the cable passes also through M, and a gutta-percha plate c_1. By this means the ends of both wires are insulated from the screw boxes R and M that contain them, and from the water outside these boxes. The two ends are brought into contact by means of small plates *n* soldered to the ends. When R and M are screwed together, the plates at *n* are pressed together, and thus close the circuit. When the diver puts on his apparatus the telephone is close to his left ear, and he can hear all that is spoken in the telephone at the surface. The diver is easily understood although the telephone is not immediately opposite his mouth when speaking, because his head is covered by the helmet. A whistle may be arranged in front of his mouth for purposes of signalling, and a single line which the diver carries with him serves the same purpose.

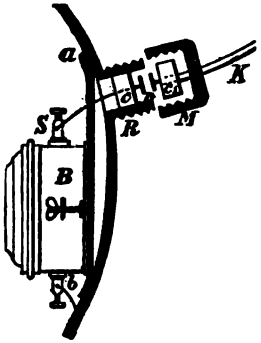


Fig. 483.—Diver's Telephone.

The Use of the Microphone for Medical Purposes.—The great sensibility of the microphone makes it of special service for medical purposes. A number of instruments have been constructed, of which we shall proceed to describe a few.

The Miophone, shown in fig. 484, has been constructed by

Boudet for examining the muscles. Behind the narrow opening of the mouthpiece B is placed the parchment membrane *m m*, which has upon its lower side the examining-knob K, and upon its upper side the carbon H. The second carbon D is held by the slide A, which can be moved up and down by the micrometer screw V. The bent paper strip at I serves as a spring which gently presses the carbon D against H. D is connected with the screw S by the support to which A is attached, and the wire shown in the figure connecting S with this support and H is connected with S_1 by means of a drop of mercury, which is placed in the hollow, and a wire. When a muscle is to be examined, the instrument is placed with its knob K upon it. In this manner it has been found that in a human muscle the pitch of the noise is suddenly raised with the natural contraction of that muscle, and continues to rise in proportion to the intensity of the contraction. The miophone is a very useful instrument for observing pathological cases, such as paralysis.

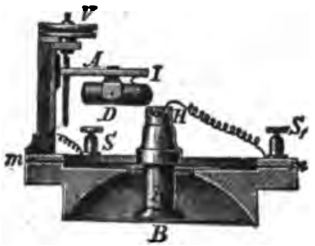


Fig. 484.—The Miophone.

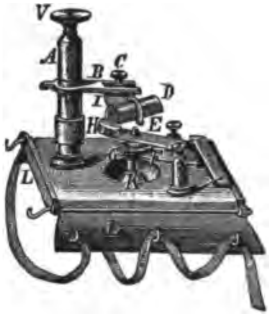


Fig. 485.—Sphygmophone.

Microphones which are used for examining the pulse are generally called sphygmophones. One of the most sensitive of these instruments is that constructed by Boudet, and shown in fig. 485. Upon a gutta-percha plate 5 by 2.5 centimetres, two springs E and F are fastened, of which the one carries the examination knob K, the other the carbon H. The spring G serves to regulate the distance of the two springs from each other, and also the pressure of K upon the artery. The movable carbon D is pressed by the paper spring I against the carbon H, and is fastened in the fork B by means of the screw C, which can be moved horizontally. By turning V, the fork, and with it the carbon, can be moved up and down A. To L L ribbons are attached, which can be tied to the arm or other portion to be examined.

For the examination of veins, where the instrument last described cannot be used, the transmission microphone is employed. This is shown in fig. 486. The carbon piece C′ is fastened to the drum, the membrane (T) of which consists of prepared pig's bladder. The drum is in connection with an india-rubber tube N, and an ivory funnel B, which is placed with a slight pressure upon the vein to be examined. In order to exclude all noises from outside, the funnel is frequently provided with a membrane furnished with an examination knob (shown in section A). The regulation of the pressure of the contact between the two carbon pieces C C′ is brought about in the following manner: The carbon C has on its upper surface a small steel needle, and the screw M is a magnetic steel spindle; the regulation of pressure is therefore due to the magnetic force of attraction. Gaiffe encloses the whole instrument in a box, which also contains the battery P.

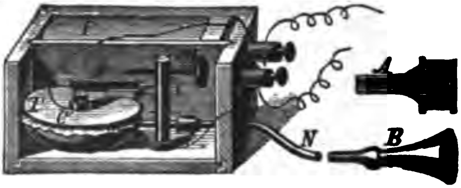


Fig. 486.—A Medical Microphone.

The audiometer, or sonometer, shown in fig. 487, is an extremely sensitive instrument used in testing the sensitiveness or acuteness of hearing in different persons. A rod marked with a scale is fastened upon two vertical supports; *a* and *c* are fixed induction coils, whilst *b* is a similar coil that can be moved along the rod; *a* has a good many turns of wire, whilst *c* has only a few. The ends of the coils *a* and *c* are connected with a microphone, so that the currents of the two coils *a* and *c* have opposite effects upon the coil *b*, which is connected with a telephone. If undulating currents are sent through the coils *a* and *c*, by means of the striking of a clock, both *a* and *c* will affect *b*, but *a* will affect it more strongly than *c* because it has a greater number of turns; thus the induction effects in *b* reproduce the striking of the clock in the telephone. But the induction effects of *a* and *c* are opposed to each other, and will consequently tend to neutralize each other the more completely the nearer the coil *b*, which has many turns, is brought to the coil *c*, which has but few. It is clear, however, that by moving *b* along the rod we must come upon a spot where the forces of *a* and *c* are in equilibrium, and where the telephone becomes mute. This position is indicated by o upon the scale, and when a person, whose hearing is to be tested, has the telephone at his ear, the nearer the coil *b* can be taken to this spot, without the listener ceasing to hear the clock, the better is the hearing of the person who is using the telephone. By examining a number of persons, say fifty for instance, a scale is obtained, for which the zero point indicates an

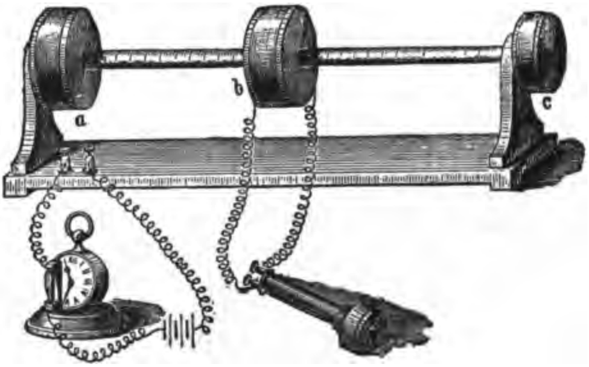


Fig. 487.—The Audiometer.

extremely good hearing, and the end of the scale almost absolute deafness. Hughes and Richardson found that the sensitiveness of hearing is increased when the breath is held, and that not only the hearing, but the strength of other organs, diminishes during illness.

The sonometre may further be used for measuring resistances. For this purpose the two coils *a* and *c* are made exactly alike, and the current coming from the battery is allowed to branch off, so that one branch flows through *a*, the other branch through *c*. The position of the coil *b* is determined when the telephone becomes mute. When the resistances on the two sides are exactly equal, this point will be the middle of the rod. It is evident that every alteration in the resistance of the one or the other branch will cause a noise in the telephone, which only ceases when the position of the coil *b* is altered accordingly. In this manner a number of known resistances may be taken and marked along the scale. If an unknown resistance is now brought into the circuit, and the coil *b* moved until the telephone becomes mute, the position of *b* will thus indicate on the scale the value of the resistance. The sonometre may also be used for examining telephones. If a number of telephones in succession are inserted in the movable coil, which is placed at the zero point of the scale, that construction will be the best that proves most sensitive to the sonometre. The method of determining the relative sensitiveness of different telephones is the same as that of determining the sensitiveness of different persons' hearing. Telephones are here substituted for persons—that is to say, in the former case the telephone remained the same, while the listener was changed; but in this case the listener is the same, and the telephone is changed.

The Induction Balance.—The induction balance, shown in fig. 488, is constructed on the same principle as the sonometre. The scales of this balance consist of two cylinders of ebonite, ten centimetres in height and three centimetres in diameter. Each of these has two coils of about 150 turns each. The coils are arranged on the cylinders about half a centimetre apart. The two upper coils are connected with a battery, a microphone, and a galvanometer, to form one circuit, as shown in the figure, and the two lower coils are connected with a telephone to form a second circuit. The two lower coils are so arranged that the induced currents generated in them oppose each other, so that if the currents are equal to each other, no sound will be heard in the telephone. Suppose this condition of things to be secured, and then let a coin be introduced into one of the cylinders between its two coils, equilibrium is immediately destroyed, and the telephone begins to sound. It can be made mute again by adjusting the movable coil on the second cylinder, or by compensating for the disturbance in another manner. If a second coin be introduced in the place of the first, equilibrium will only be maintained when the second coin has the same form, weight, and composition as the first. This method has been made use of for the examination of alloys, a description of which has been given in the *Philosophical Magazine*, 1879, and other periodicals. The balance is so sensitive that different results are even obtained when the physical condition of the coin only is altered, as for instance by hammering, casting, etc. The induction balance is further used for the discovery of ores under ground, torpedoes

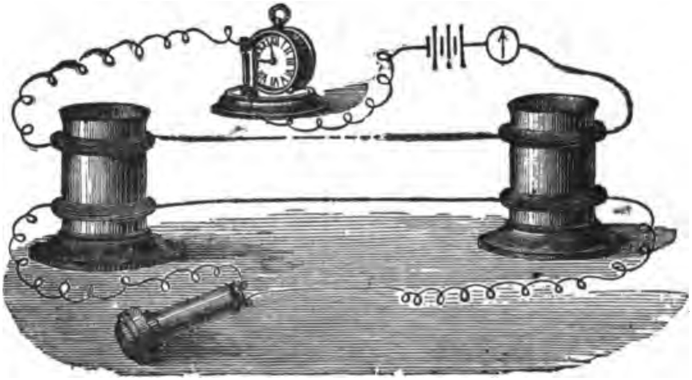


Fig. 488.—Hughes' Induction Balance.

and other metallic bodies in the sea, projectiles in the human body, etc., etc. MacEvoy's Submarine Finder, for the recovery of torpedoes, anchors, iron ships, and all kinds of iron material at the bottom of the sea, which is shown in fig. 489, is only an induction balance in a somewhat altered form. P P′ are the coils inserted in the primary circuit, B represents the battery, and J an interrupter. The secondary coils S S′ are connected with the telephone T. When quickly succeeding current impulses are sent through the coils P P′, induced currents are generated in the spirals S S′, which neutralize each other, because they affect the telephone in opposite directions; thus the telephone is made mute when the position of the coils is regulated accordingly. If now the coils P′ S′ be brought near a metal mass, equilibrium is at once destroyed, and the telephone indicates, by giving out sounds, the presence of a metal in a particular spot—for instance, the spot where a torpedo lies hidden, etc.

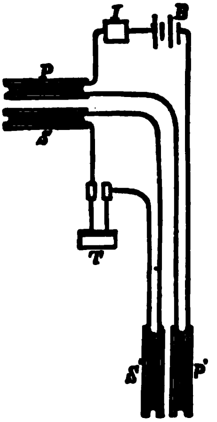


Fig. 489.—The Submarine Finder.

The induction balance has been used in various forms by army surgeons as an electric ball probe. For this purpose Hughes makes one pair of the coils movable, and, having adjusted the balance, conveys this pair over the portion of the body into which the projectile entered. As soon as the coils come near the projectile, the telephone begins to sound. By moving the coils about this portion, the exact spot may be found where the projectile lies hidden, because the telephone will sound loudest at that spot. The depth of the projectile may also be detected. The coils for this purpose are left at that place where the telephone sounds loudest; it is then silenced by bringing a piece of lead, equal to that supposed to be in the wound, near the fixed coil. If the lead piece is at the same distance from the fixed coil as the coil on the body is from the projectile, equilibrium is again restored, and the telephone becomes silent. The distance of the lead from the fixed coil gives the depth to which the ball has entered.

Statistics.—The *Bulletin International* publishes the following statistics respecting the number of networks of telephones and of subscribers in Europe on the 31st of December, 1885:

	No. of Networks.	No. of Subscribers.
Great Britain	89	15,114
Germany	91	14,733
Italy	16	8,346
France	20	7,175
Sweden	15	5,705
Russia	20	5,280
Switzerland	36	4,900
Belgium	7	3,365
Austria	11	3,032
Holland	8	2,493
Denmark	2	1,370
Spain	3	594
Portugal	2	350
Total	320	72,457

No telephones have as yet been established in Turkey, Servia, Bulgaria, Roumania, Greece, Montenegro, or the Grand Duchy of Luxemburg.

In Asia and Africa several networks of telephones have been established, viz., at Rangoon, Singapore, Columbo, Madras, Calcutta, Bombay, Maulmain, as well as in the Mauritius.

In Egypt, telephonic services have been established at both Alexandria and Cairo, and number 431 subscribers. In the United States the telephone is in general use, and the fifteen principal cities alone contain 30,000 subscribers. At Buenos Ayres there are 1,544 subscribers, and 389 at Monte Video.

PHOTOPHONE, PHEROPE AND PHONOGRAPH.

Properties of Selenium.—In 1817, Berzelius discovered selenium, which in its chemical and physical properties resembles sulphur and tellurium. Selenium heated for sometime to 100° turns into a crystalline greyish mass. Knox pointed out, in 1837, the conductivity of molten selenium for electric currents. Many found that the conductivity of selenium is considerably influenced by light. Numerous physicists, as Willoughby-Smith, Draper, Sabine, Bell, Adams, Werner Siemens, and others have pursued investigations in the subject, most of them using the galvanometer for their experiments. Bell, however, used the telephone for detecting the alterations of resistance, and this led to the construction of the photophone. As selenium offers an unusually great resistance to the passage of the electric current, only very thin layers can be inserted in a circuit when the telephone is to be heard, because the resistance of the induction coil in the telephone has to correspond with the resistance of the circuit. The selenium surface has, however, to be large, in order that it may be as much as possible affected by the light. Bell and Tainter tried, therefore, to produce some preparation that answered the above conditions—*i. e.*, they endeavoured to obtain a sensitive selenium cell. Bell says, in his first memoir on this subject, that he had constructed more than fifty different selenium cells with which to experiment. Such a selenium cell is given in fig. 490. It consists of a great number of brass discs (1 . . . 10), which are insulated from each other by mica plates (the white strips in the figure). The mica discs have a smaller diameter than the brass discs, so that a circular space is left between two succeeding brass discs, which is intended for the reception of the selenium. The whole pile is now heated to the temperature at which selenium melts. A stick of selenium is then rubbed over the hot surface, and the molten selenium enters the circular spaces, marked in the figure as dark surfaces. The even brass discs are connected with a conductor N, and the odd-numbered discs with a second conductor M. In this manner a number of selenium elements are joined parallel; that is to say, a pile is obtained, which is of small resistance, although its surface is large. Such a pile had 1,200 ohms of resistance in the dark, and only 600 ohms by daylight.

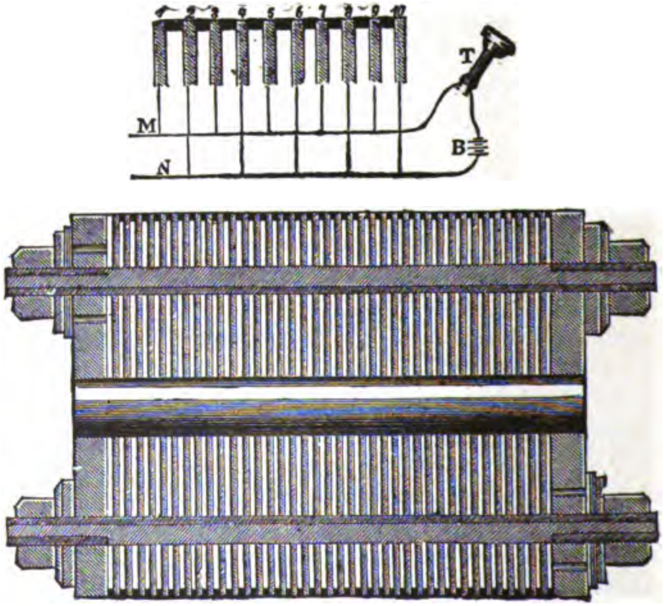


Fig. 490.—Bell's Selenium Cell.

The form which Mercadier gave to his selenium element is shown in fig. 491. Two very thin brass bands, *a* and *b*, of 0.1 millimetre thickness, are used for this purpose. The former is indicated by the full lines, the latter by the dotted lines. The brass bands are insulated from each other by having parchment strips between them, represented by the white spaces in the figure. The end of brass band *a* is fastened to the brass plate *d d*, and the strip *b* is connected with the brass plate *c c;* so that all the even coils are connected with one plate, and all the odd coils with the other. The complete coil is placed between wooden bars, which are held together by the screws *n n*. The clamp A is connected with the metal plate C C, the screw B with the plate *d d*. The block thus obtained is polished at its front side, and then tested with a galvanometer to see whether the two metal coils are insulated from each other throughout their length. The block is then heated in a sand bath until it has reached the temperature at which selenium melts. One side of the block is then coated with a thin layer of selenium. In order to protect this layer of selenium, it is covered either with a thin mica plate or a layer of varnish.

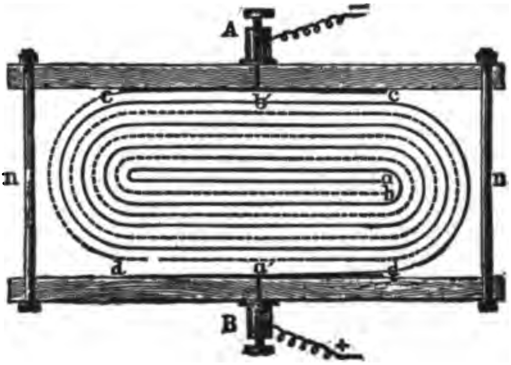


Fig. 491.—Mercadier's Selenium Cell.

If the telephone is to form a sensitive and effective apparatus for noticing the alterations of resistance in selenium, it must be influenced by currents that change their intensity suddenly and repeatedly, as gradual changes affect the telephone as little as they do the secondary coils of induction coils. It is therefore necessary that the resistance in the selenium shall change rapidly; *i. e.*, that the selenium element shall be exposed to a rapidly intermittent illumination. Such intermittent changes of light can be produced in different ways; one method is to intercept the rays of light by means of an opaque disc, which has openings near its periphery, and is then made to rotate rapidly. If the selenium element be connected with a battery and a telephone to form a circuit, a sound will be heard in the telephone, the pitch of which is determined by the number of intermissions of the light in a unit of time. Bell and Tainter in their experiments placed the receiver 213 metres from the sender; if, however, the source of light is sufficiently powerful, this distance may be considerably increased. The apparatus, as described, allows correspondence to take place between persons at two places distant from each other, without their being connected with each other by leads. An alphabet may be composed of long and short sounds in the same manner as the alphabet of the Morse apparatus, which consists of strokes and points. A simple apparatus by means of which this may be obtained is shown in fig. 492. The disc S, which is perforated at its periphery, is made to rotate uniformly, and thus changes the passing rays of light into intermittent rays, which, owing to the alterations of resistance in the selenium cell, cause the telephone at the receiving station to sound. These sounds may be made long and short at pleasure

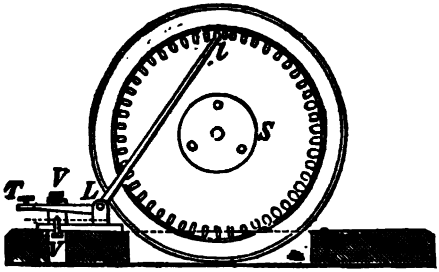


Fig. 492.—The Sender of a Photophone.

by preventing the rays of light from passing the disc S through a smaller or greater number of holes. The key T, which moves about L, and ends in the pointer L *l*, serves this purpose. When the key is at rest, *i. e.*, when it presses against the upper screw V, the end of the pointer at *l* covers that opening of the disc which lies opposite the source of light, and hinders the passage of the rays of light. When the key is pressed down the pointer moves to the left, and the rays are allowed to pass as often as an opening comes opposite the source of light. By holding down the key a longer or shorter time, shorter or longer sounds are produced in the telephone at the receiving station.

The Photophone.—To such apparatus, in which sound is produced by means of an ordinary ray of light, Bell gave the name

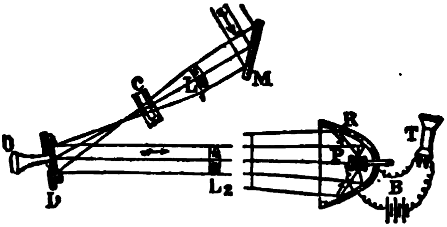


Fig. 493.—The Photophone.

of photophone. The photophone may not only be used for the transmission of sounds, but also for the transmission of spoken words. Bell obtained this result by making the beam of light, which a mirror reflects, vibrate, the vibrations being of the same kind as those produced by speaking to a membrane. Bell uses a thin mica or glass plate as membrane or diaphragm, which, by being silvered, serves at the same time as a mirror. The apparatus must be arranged as shown in fig. 493. M is a mirror, which throws the rays of light (of the sun, an electric lamp, etc.) upon the thin silvered plate or diaphragm D; these rays are reflected in the direction indicated by the arrow; the lenses L_1 and L_2 serve to concentrate the rays. At the receiving station the rays of light fall upon a parabolic concave mirror R, and are thrown from there upon the selenium cell P, which is inserted in the circuit of the battery B and the telephone T. If O is now spoken into, the diaphragm D begins to vibrate, and causes the rays of light to vibrate also. The selenium cell P will then be exposed to a change of illumination, which corresponds to the vibrations of sound. The resistance in the selenium cell, and therefore the current, is altered accordingly, and consequently the membrane of the telephone makes the same vibrations as the diaphragm D; *i. e.*, the telephone reproduces the words spoken against D. Fig. 494 represents the sender in perspective. The rays of light falling upon the mirror M are reflected, collected by the lens L_1, and conveyed to the mirror diaphragm D; from here they pass through the lens L_2, and then reach the receiving station.

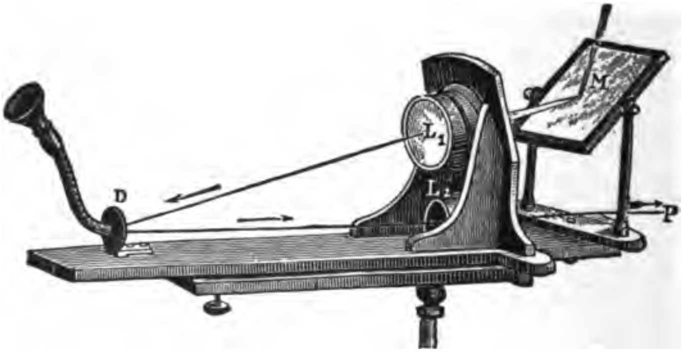


Fig. 494.—The Sender of a Photophone.

Bell's experiments and publications regarding the photophone stimulated further investigations. It was found that the transmission of sound was possible without using selenium cells and galvanic batteries, and that non-luminous heat-rays were capable of producing sound. The latter fact caused Mercadier to use the word *Radiophone*, instead of photophone. A thin plate of any material serves as receiver in the radiophone, the sounds produced by this plate being transmitted by means of a tube to the ear. Mercadier altered the sender (or sounding apparatus) by substituting for the perforated disc a glass disc, covered with black paper, in which openings in the form of concentric circles were cut. By this arrangement those noises were avoided which, in Bell's arrangement, were caused by the friction of the air in the holes. It was soon found that the receiver's plates were not made to vibrate transversely by the intermittent rays of light, but vibrated like ordinary sounding-plates. One and the same plate, for instance, is capable of giving the highest and deepest notes equally well; the breadth and thickness of the plate do not influence the pitch nor the sonorousness or timbre of the sounds. When several intermittent rays of light, having varying velocities, meet the plate, whole sounds are produced by it. Except as it affects the intensity of sound, it is immaterial of what substance the plates are made; but the slightest alteration in the surface makes a considerable difference. Scratched or oxidized surfaces increased the intensity of sound very much, whilst a silvered glass plate gave no sound at all. As a rule, those plates proved most effective which absorb the rays strongly, but do not reflect them well. Very good results were obtained by using plates the surfaces of which were covered with Indian ink, platinum black, or soot; paper which in its ordinary condition gave no sounds, did so when the illuminated surface was covered with soot. A very sensitive receiver is obtained by coating a mica plate with soot.

The great sensitiveness of surfaces coated with soot caused Tainter to form the idea of substituting soot for the selenium in a selenium cell. For this purpose silver is precipitated upon a glass plate P (fig. 495); and portions of this precipitate are removed, so that the places free from silver form a zigzag line *z z*, which is filled up with soot. The zigzag-shaped soot strips divide the silver coating into two portions which can be connected, by means of the clamps K K, with the battery and the telephone. When intermitted rays of light strike upon the face of such a cell, loud sounds are produced in the telephone, the cause of which we shall now proceed to explain.

When use is made of a selenium cell, which is inserted along with a telephone in the circuit of a battery, the light-rays falling upon the selenium cell alter the conductivity of the selenium at the same rate as the intermittence of the rays. It follows that the current will also vary in the same way, and the telephone give out sounds; that is, the words spoken against the plate of the sender, which are the cause of the disturbance or intermission of the beam of light, will be reproduced in the telephone. By using a selenium cell the effect of light is made to produce sound.

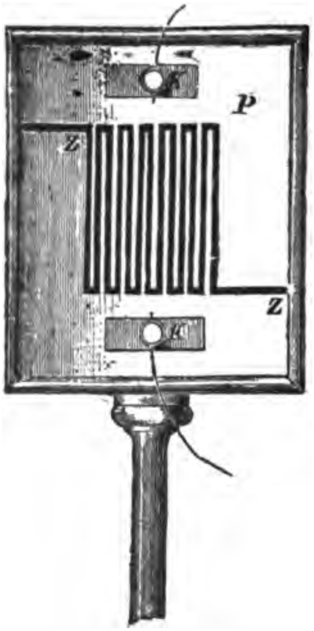


Fig. 495.—The Carbon or Soot Cell.

Now when a simple plate, prepared as we have described, and furnished with a tube, is used as a receiver, such as a mica plate covered with soot, neither battery nor telephone need be used. The illuminated surface of the receiver does not cause a second apparatus (the telephone) to sound, but it is the plate itself which sounds. The light effect, therefore, that takes place with the soot-covered mica plate is not in all respects similar to that in the selenium cell.

Several physicists have experimented in order to find out what constituents of light really act upon the plate, whether the light or heat rays. For this purpose intermittent rays were allowed to pass through a solution of iodine in sulphide of carbon, which has the property of absorbing the rays of light, but allowing heat-rays to pass. It was found that the sounding of the plate was not influenced by inserting the solution. The plate, however, emitted no sounds when, instead of the iodine sulphide solution, a solution of alum was used. The latter solution absorbs the heat-rays, but allows the rays of light to pass. Mercadier used a red-hot copper plate as a source of light for producing intermittent rays, and succeeded in making the receiver give out sounds. He then allowed the plate to cool gradually, so that it could be no longer seen in the darkened room—*i. e.*, no luminous rays were sent out; in spite of this the sounding of the receiver remained still audible. From these and similar experiments it follows that the effect is not due to the light-rays, but to the heat-rays. Mercadier proved this by decomposing intermittent rays of light into their constituents by means of a prism; the spectrum thus received was examined by a receiver, the plate of which was covered up to a small slit. The different constituents of the intermitted light were examined in turns, and the same result obtained.

Although it is proved in this manner that heat-rays cause the plate of the receiver to vibrate, it is still necessary to ascertain the nature of these vibrations. It has been mentioned already that the plate of the receiver does not vibrate transversely as ordinary sounding-plates. Bell has given the following explanation: When the intermittent beam strikes upon the plate of the receiver, the particles are alternately heated and cooled; when they are heated they expand, and consequently the intervals which are filled with air are diminished; when the light is intercepted the particles are cooled, and the spaces between them enlarged. Air is squeezed out from the interstices between the particles in the first case, and drawn in, in the latter; the enlarging of the intervals causes rarefaction of the air in the soot layers, and the outer air rushes in; the contraction of the intersticial spaces causes condensation and escape of the air they contain. These two effects are still further increased by the heating and cooling of the air in the intervals alternately, whereby the volumes are alternately increased and diminished. By these means alternate waves of compression and rarefaction are produced in the surrounding air, and it is to this that the sound which is emitted owes its existence.

Cause of the Microphonic Action of Selenium Cells.—The remarkable property possessed by crystalline selenium of having its electrical resistance varied by the action of light, has been the subject of many investigations. Of these the best known and by far the most exhaustive are the researches of Professor W. G. Adams and Mr. R. E. Day, an account of which was published in the *Phil. Trans.* of 1877. As the result of many experiments, these gentlemen were led to form the opinion that "the electrical conductivity of selenium is electrolytic." The principal reasons given for this conclusion are: "(1) that the resistance of selenium bars appeared to depend upon the E. M. F. of the battery employed, being generally diminished as the battery power was increased; (2) that the resistance of a bar A B was generally not the same for a current in the direction A B as for a current in the direction B A; (3) that the passage of a battery current was always followed when the battery had been disconnected by a secondary or polarization current in the opposite direction, it being clearly proved that this secondary current was not due to any thermo-electric action, either in the selenium itself or in any other part of the circuit."

The action of light in altering the conductivity is supposed by these experimenters to arise from a modification of the crystalline condition of the substance when exposed to light. The following are their words on this point: "Light, as we know, in the case of some bodies tends to promote crystallization, and when it falls on the surface of a stick of selenium, tends to promote crystallization in the exterior layer, and therefore to produce a flow of energy from within outwards, which under certain circumstances appears in the case of selenium to produce an electric current. The crystallization produced in selenium by light may also account for the diminution in the resistance of the selenium when a current from a battery is passing through it, for in changing to the crystalline state selenium becomes a better conductor of electricity."

Sabine, Siemens, Moser, Bidwell, and lastly Mr. C. E. Fritts, of New York,* have investigated and discussed these most remarkable properties.

Dr. James Moser's theory may be stated as follows:

There is always imperfect contact between the metallic electrodes and the selenium, which together constitute a so-called "selenium cell." Selenium reflects the invisible portions of the spectrum, absorbing principally the visible or illuminating rays, the vibrations thus taken up assume the form of heat, and the temperature of the selenium cell is thereby raised.† In consequence of this rise of temperature the selenium expands; it is accordingly pressed into closer contact with the electrodes, and, as in the case of the microphone, the resistance of the system is proportionately diminished. When the cell is screened from the light, the absorbed heat is quickly radiated away; the selenium contracts to its former volume, and the original degree of resistance is restored. Thus, according to Dr. Moser's paper, the whole mystery is easily and completely explained.

Respecting this explanation, Mr. Shelford Bidwell remarks that the theory can be submitted to a very simple and conclusive test. If it is true that the observed effects are due merely to a rise of temperature, then it is clearly immaterial whether such rise of temperature is brought about by the heating action of light, or by the direct application of heat in the ordinary way. Instead of exposing a selenium cell to the light, let it be enclosed in a dark box and warmed over a gas-burner; then, if the theory be correct, the resistance of the cell should at once begin to fall. This, however, is not found to be the case. Mr. Bidwell had in his possession a number of selenium cells the resistance of which is immediately diminished by the smallest accession of light; but in the case of all of them (except one) the immediate effect of the direct application of heat is not a fall, but a rise in the resistance. When the temperature of the cell reaches a point which is in general a few degrees higher than the average temperature of the air a maximum resistance is attained; and if the heating is continued the resistance begins to decrease.

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* See *Electrical Review* of March 7, 1885.

† "Selenium," Dr. Moser says, "is heated by light."

Mr. Bidwell maintains that the supposition that light produces its effects by heating is further negatived by the fact that a comparatively high degree of temperature is required to bring down the resistance of the cell to the point to which it is instantly reduced by exposure to a strong light. When a selenium cell is for a moment exposed to sunlight, it does not become perceptibly warm to the touch; but the amount of dark heat necessary to effect the same reduction in its resistance as is caused by a moment's sunshine, would certainly render it too hot to handle.

The best results with a selenium photophone are said to be obtained when the heat-rays of the spectrum are excluded, as by filtering the beam of light through a solution of alum. Dark radiation does indeed, *per se*, diminish the resistance of selenium; but the diminution due to dark radiation is to some extent masked by the rise of temperature which accompanies it, and which generally tends to produce the opposite effect. In its peculiar sensitiveness to the visible part of the spectrum, selenium seems to stand almost alone.

In the case of the carbon photophone there can be no doubt that the effects are due to heat only. In the recent publication by Mr. C. E. Fritts, above referred to, a new and ingenious method of constructing selenium cells has again directed attention to the subject, and led to the discovery that sulphur exhibits a similar behavior when under the influence of light, though not to the same extent as selenium.

The Telephote, or Pherope, is an instrument to which the ambitious purpose has been assigned of enabling a person living, for instance, in London, to see by telegraph a picture or an occurrence, such as a race, taking place at York. Although the problem is far from being solved, Messrs. Ayrton and Perry have been able to show that it is within the range of possibility. We cannot do better than give a quotation from a lecture by Professor Perry on this subject:—"I have a little selenium cell at York on a certain part of this picture, and at London I can throw at a corresponding place on this screen a square of light; and suppose that the illumination of this square is governed by a little movable shutter, which is attached to the needle of a galvanometer. Now when light falls on the selenium at York, an immediate change occurs in it, so that more current flows to London, and this opens the shutter. The London square is then bright when the York selenium is in bright illumination. When the York selenium is in shade or darkness, you see that the London square is in corresponding shade or darkness. (Experiment shown.) Now suppose that we form an image of this girl with her skipping-rope at York, and cause a selenium cell at York to travel across her image, and suppose that this mirror at London moves so as to cause the illumination which passes the shutter to traverse this London screen isochronously—an operation performed in several telegraph instruments. Then, whenever this cell reaches a dark, or shady, or bright place in the image at York, there will be darkness, or shade, or brightness at the corresponding place in London. And now suppose that this motion is effected rapidly enough, you are all aware that if the shutter is only quick enough in its answering motions, the image of the part of the screen at York traversed by the cell will be faithfully reproduced, and will remain on the retina at London as a distinct picture in black, and grey, and white, just like a photograph. With then, perhaps, forty such cells as this all moving in the way spoken of, or a smaller number rotating on a radial arm, it would actually be possible to show at London, not merely an image of a girl at York, but an image of a girl skipping."

Professor Perry used the model shown in fig. 496 to explain the principle. By means of a lantern L an image is thrown upon the screen S: for instance, a ribbed pattern consisting of dark and light stripes. By means of a string a selenium cell D can be moved quickly over it; one end of this string is fastened to the movable sector *h b*, so that the selenium cell and this sector, by pulling the free end of the string, are moved perfectly isochronously. The mirror *a* is fastened to the support *b*; opposite to the mirror is placed the screen *s*, bent to the radius of *h b*. The source of light *c*, the rays of which are thrown by the mirror upon screen *s*, has a peculiar construction; before the rays reach the mirror they have to pass a kind of galvanometer; *i. e.*, they have to go through the hollow of a coil in which a small magnetic needle swings. Upon this needle is fastened a screen of sheet aluminium, coated with lamp-black, called a darkener, which places itself, according to the position of the needle, either crosswise or parallel to the longitudinal direction of the space of the spiral, or takes up a position between the two. When the darkener stands crosswise in the hollow space of the spiral, it entirely cuts off the passage of the rays of light; when it stands parallel, almost all the rays are allowed to pass; and in its middle position, a portion only of the rays pass. But as the coil is inserted, with the selenium cell D, in the circuit of a battery, the position of the magnetic needle, and also that of the darkener, will depend upon the strength of current. The darkener is fastened upon the magnetic needle in its crosswise position; that is, when the rays of light are completely intercepted, and when the current has its minimum intensity. By this arrangement the strength of current is only varied by the varying re-

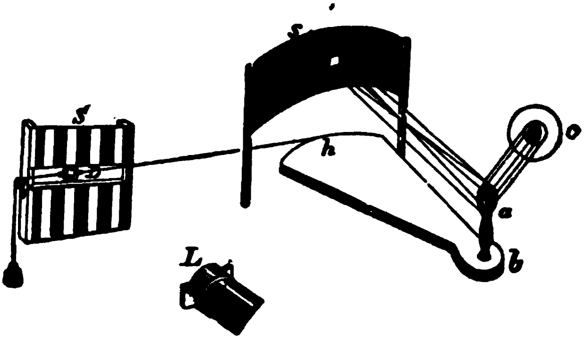


Fig. 496.—The Telephote, or Pherope.

sistance of the selenium cell, which varies with the illumination. If, therefore, the selenium cell happens to be upon a light stripe of the screen *s*, its resistance will be least, and the strength of current greatest; the darkener will, therefore, place itself parallel to the longitudinal direction of the hollow space in the coil. The rays of light, which are allowed to pass freely, then fall upon the mirror *a*, and are thrown from there upon the screen *s*, and a light stripe will be produced. If the selenium cell is moved till it reaches the next light stripe, the mirror *a* will again produce a light stripe upon screen *s*; the position of the light stripes upon *s* will have to correspond to those with S, because the selenium cell D and the mirror *a*, fastened upon *h b*, are moved in the same manner. As often as the selenium cell reaches a dark stripe its resistance becomes highest, therefore the strength in the coil lowest. The darkener then places itself crosswise, and allows no ray of light to fall upon the mirror *a*; the screen, therefore, will also remain dark. By moving then the selenium cell D over the picture on the screen S, corresponding pictures might be produced on the screen *s*. A faithful copy of the image of S will be produced on *s*, when the selenium cell is moved so quickly that the produced light stripes on *s* succeed each other at shorter intervals than those required by the human eye to perceive the several pictures separately. The image of the second and third light stripes will be already on the screen, while the impression of the first remains still on the retina.

It need hardly be said that the synchronous motion of mirror *a* and selenium cell D would have to be brought about by other means than a string, as in the model; for this purpose the phonic wheel might be used, for instance. For the reproduction of a larger picture, such as a skipping girl, a greater number of selenium cells are required, and the sources of light have to be arranged accordingly.

The Phonograph.—We shall conclude the subject of telephony with the description of the phonograph, not that electricity is in any way concerned in its action, but because of its close relationship with the telephone, and because it proves that the oscillations of a tympanum, like the disc of a telephone, in one direction only, are capable of producing all the effects of sound.

The phonograph was invented by Edison, and one of the forms which he gave to it is shown in fig. 497. The brass cylinder A is fastened upon a shaft, one end of which has a handle, and the other end a heavy fly-wheel G. In one half of the axis, namely, that nearest the handle, and in the brass cylinder, screws are cut, the threads of which are exactly alike; that is to say, the threads on the cylinder are exactly of the same breadth as those of the shaft, so that the same number in both go to the inch. As the screw axis lies in a female screw fastened to the support, when the handle is turned the cylinder will be moved in the direction of the axis. A movable support S is placed on the frame of this apparatus, which carries a mouthpiece B with a membrane M, arranged and fastened to each other, as in telephones. The spring *f* is screwed at one end T to the support S, and carries at its free end the steel pin *s*. The connection of this elastic pin with the membrane is brought about by means of the india-rubber tube *c*. When the membrane M is made to vibrate by speaking into B, *s* vibrates in the same manner. To register speech with this apparatus the brass cylinder is covered

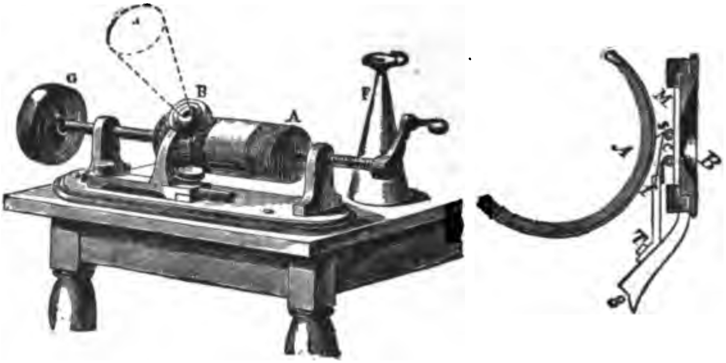
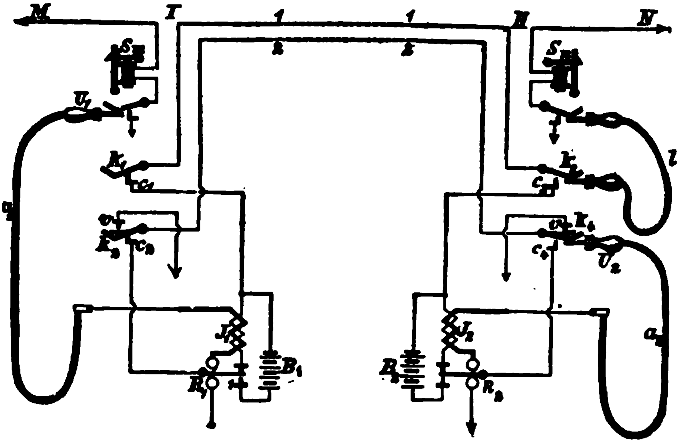


Fig. 497.—Edison's Phonograph.

with tinfoil, or a thin copper plate; the pin *s* is then adjusted, and the cylinder made to rotate, whilst at the same time words are spoken into the mouthpiece. The membrane, and with it the pin, begin to vibrate, the latter tracking signs upon the moving tinfoil, which correspond to the vibrations produced by speaking. The worms of the cylinder and its axis being alike, the pin travels with the same velocity from the one to the next thread as the cylinder, by means of its screw axis, moves sideways. If the phonograph is to reproduce the words spoken, the pin is taken off and the cylinder moved back until it arrives at the commencement of the coil; the pin is then again placed on the cylinder, and the latter is made to rotate with the same velocity and in the same direction as before. The effect of the apparatus is increased when the funnel F is placed upon the mouthpiece. The pin, by going over the signs it traced before, will reproduce the spoken words; that is to say, it will vibrate again as it did when words were spoken in the mouthpiece, and will cause the membrane to vibrate. The membrane reproduces the words audibly, and may be heard in every part of a large room.



THERMO-PILES.

Thermo-electricity is electricity produced at the junction of two metals, or at a point where a molecular change occurs in a bar of the same metal, when the junction or point is heated above or cooled below the general temperature of the conductor. Thus, when wires or bars of metal of different kinds, as bismuth and antimony, are placed in close contact, end to end, and disposed so as to form a periphery or continuous circuit, and heat then applied to the ends or junctions of the bars, electric currents are produced. The principle of the arrangement is shown in fig. 498, in which the bars marked *a* are antimony, those marked *b* bismuth. The junctions 1, 3, 5, 7 are to be at one temperature, the junctions 2, 4, 6, 8 at another. G is a delicate galvanometer which measures the force of the current produced. The thermo-electric battery, or pile, an apparatus much used in delicate experiments with radiant heat, consists of a series of little bars of antimony and bismuth (or any other two metals of different heat-conducting power), having their ends

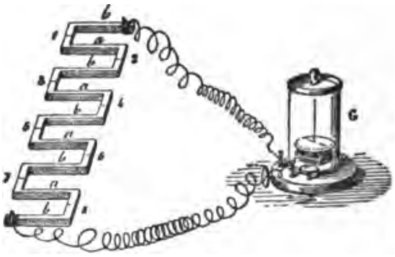


Fig. 498.—Thermo-Pile.

soldered together and arranged in a compact form; the opposite ends of the pile being connected with a galvanometer, which is very sensibly affected by the electric current induced in the system of bars when exposed to the slightest variations of temperature. To the combined arrangement of pile and galvanometer the name of *thermo-multiplier* is given. Two metal bars of different heat-conducting power having their ends soldered together, and the combined bar then usually bent into a more or less horse-shoe or magnet form, for the purpose of bringing their free ends within a conveniently short distance. designated a thermo-electric pair, are much used in thermo-electric experiments. But as the electric current developed in a single pair is very weak, a considerable number are usually combined to form a thermo-electric pile or battery. Bismuth and antimony are the metals usually employed, the difference in electro-motive force being greater between them than between any other two metals conveniently obtainable.

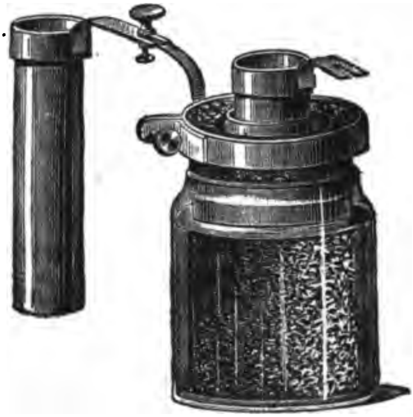


Fig. 499—The first Bunsen's Patent.

The first who pointed out that a current was generated when the joints of different metals were kept at different temperatures was Seebeck, in 1821, and the apparatus he used for the purpose is shown in fig. 500. A piece of copper K, bent in the shape seen in the figure, was placed on a block of bismuth *a b*, having a movable magnetic needle *n s;* as soon as the temperature was altered by either heating or cooling the junctions of the two metals, the deflection of the needle indicated a current which continued to flow as long as the difference of temperature was maintained at the junctions. The needle indicates the direction in which the current flows. If, for instance, the north end *b* be heated, the needle moves east, showing that at the heated junction the current flows from the bismuth to the copper, at the cold junction from the copper to bismuth. Not only will bismuth and copper generate currents, but almost any two metals will do the same. Seebeck arranged a table of metals in thermo-electrical order, as follows:

+Antimony
Arsenic
Iron
Zinc
Silver
Gold
Tin
Lead
Copper
Platinum
Cobalt
Nickel
Bismuth.

This order only holds good for temperatures within certain limits, and the structure of the metals, etc., ought to be taken into account. Bismuth and antimony, being farthest from each other in the list, are best for the construction of thermo-electric elements. The power of any element as a rule increases with the increase of difference of temperature between the two junctions up to certain limits, and if the difference of temperature between be made still greater, the current may cease altogether, or flow in an opposite direction to that in which it flowed when the difference of temperature was not so great. The limit is different for different couples. In the case of a copper-iron pair the neutral temperature is 280°, and beyond this difference there is an inversion of the current.

Thermo-electric elements generate constant currents as long as the temperature at the junctions is kept constant. The easiest way to secure this is to place one of the junctions in boiling water, the other in melting ice. The former will have a constant temperature of 100° C., the latter a constant temperature of 0°. The electro-motive force of the thermo-electric elements compared with that of the galvanic elements is very small: for instance, the electro-motive force of pure silver and copper is about $\frac{2}{1000}$ of a Daniell's element. If we take this electro-motive force as unity, we obtain the following values:

Silver and Bismuth	32.9
" " German silver	5.2
" " Mercury	2.5
" " Lead	1.0
" " Antimony	9.87
" " Tellurium	179
" " Selenium	290

Alloys may also be used for thermo-electric purposes, but they do not follow exactly the order which might be expected from their relation to the metals from which they are derived. Seebeck obtained the following order for the principal alloys:

Bismuth
Lead
Tin
1 bismuth, 3 tin
1 bismuth, 3 lead
Platinum, No. 2
1 bismuth, 1 lead
Gold, No. 1
Silver
1 bismuth, 1 tin
Zinc
3 bismuth, 1 lead
1 antimony, 1 copper
1 antimony, 3 copper
1 antimony, 3 lead, 3 antimony, 1 lead
1 antimony, 3 tin, 3 antimony, 1 tin
Steel (cast)
Steel (rod)
3 bismuth, 1 tin
1 bismuth, 3 antimony
Antimony
1 antimony, 1 tin
3 antimony, 1 zinc.
+

The thermo-electric elements can be united to form batteries, as shown in fig. 501, but care must be taken that the even numbers 2, 4, come on one side, the odd numbers, 1, 3, 5, on the other side, so as to be convenient for heating the one and cooling the other. Such a battery is usually called a thermo-pile.

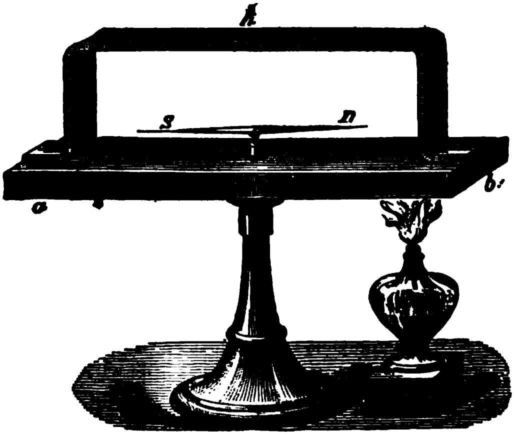


Fig. 500.—Seebeck's Thermo-Electric Apparatus.

Thecir cumstance that the electro-motive force of a thermo-pile is proportional to moderate differences of temperature, makes it a valuable and delicate instrument for measuring temperature. For this purpose the wires of the pile are connected with a very sensitive galvanometer. The slightest difference of temperature generates a current; and the strength of this current, which is proportional to the difference of temperature for a considerable range, is indicated by the deflection of the needle. According to Melloni, $\frac{1}{5000}$ of a degree can be measured with this instrument, a minute difference which, of course, cannot be obtained with any other thermometer. Thermo-piles are constructed of different shapes;

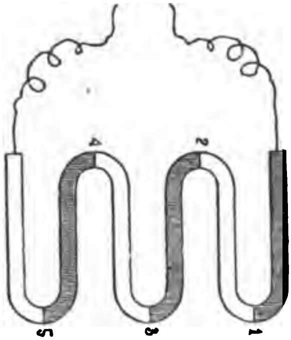


Fig. 501.—Thermo-Electric Battery.

but the form generally used for experiments on heat is that of a cube (fig. 502). All the even junctions lie on one side and the uneven on the other side. The complete apparatus is shown in fig. 503. For certain purposes, *e. g.*, for ascertaining the comparative temperature at any given lines in the spectrum, thermo-piles are used having the even and odd junctions arranged in straight lines. In some cases the thermo-electrical needle is of service. This consists of one element, the junction of which is pointed, and the free ends connected with a galvanometer. With it the condition as regards heat of animal and vegetable textures is investigated.

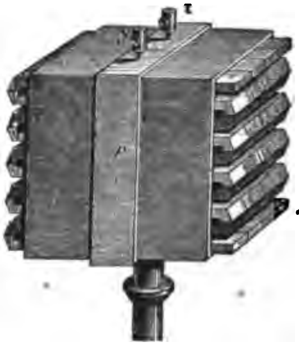


Fig. 502.—The Thermo-Pile.

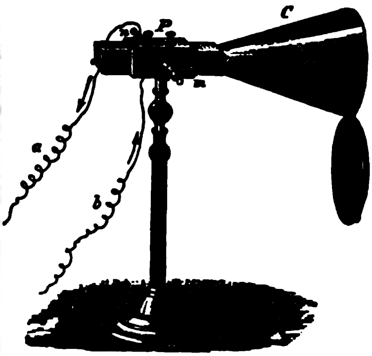


Fig. 503.—Melloni's Thermo-Pile.

Economic Value.—In principle the generation of electricity by means of difference of temperature is preferable to its generation by means of galvanic batteries or electric machines. In galvanic elements, zinc, which is obtained from the zinc ore by using coal, is consumed. Electric machines, as a rule, are driven either by steam or gas, both of which receive their energy indirectly from coal. In thermo-electric elements, however, the stored heat of the coal is directly converted into electricity. In spite of this favorable circumstance, thermo-piles are seldom used in practice, owing to the fact that the thermo-electric elements as constructed at present are capable of furnishing only very weak currents. Antimony and bismuth were first used for the construction of thermo-piles because these stand farthest from each other in the thermo-electric series. Bunsen obtained a more powerful element by using an alloy, viz., copper pyrites. Although such an element is certainly more powerful than an antimony-bismuth element, its construction is very difficult, owing to the irregular expansion of the junctions when heated. By melting and casting the copper ore into the desired form it loses its natural structure, and the E. M. F. of the elements is considerably diminished thereby. Markus used alloys which are far distant in the thermo-electric series, and also are capable of bearing high temperatures. The thermo-pile which he constructed in 1864–65 obtained a prize from the Vienna Society for the promotion of science. The negative metal of the pile is an alloy similar to German silver. It consists of 10 parts of copper and 6 parts of zinc and nickel. The positive metal consists of 12 parts of antimony, 5 parts of zinc, and 1 part of bismuth. The negative metal is formed into blocks, the positive into three bands connected by

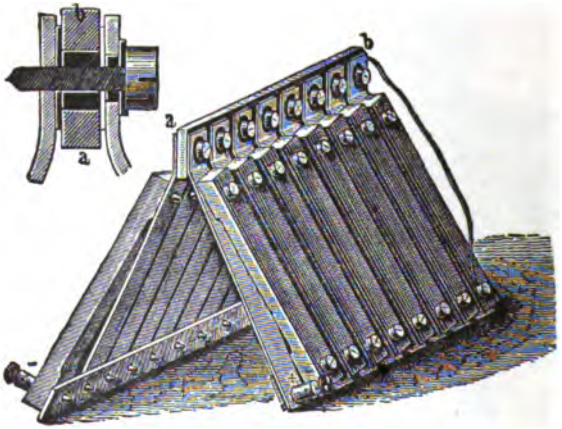


Fig. 504.—Markus's Thermo-Pile.

means of screws. A number of such elements are fastened to an iron bar *a b* (fig. 504). Mica plates are placed between the elements and bar in order to insulate them. The iron bar *a b* is heated, and the lower ends are immersed in water. A battery consisting of 130 elements is capable of furnishing 25 cubic centimetres of oxy-hydrogen gas per minute, or of maintaining a platinum wire of 0.5 millimetre in cross section at a red heat. The E. M. F. of an element is equal to one-twentieth of that of a Daniell's cell. The resistance in the pile very soon increases considerably, as the two alloys at the places of contact become easily oxidized.

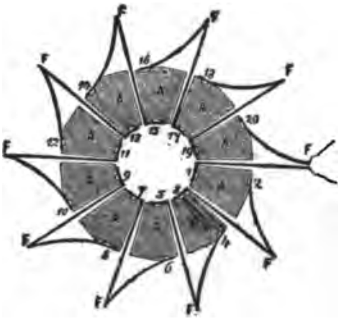


Fig. 505.—Clamond's Thermo-Pile.

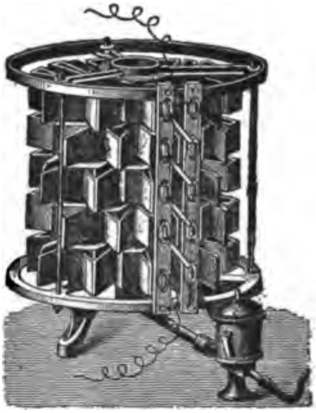


Fig. 506.—View of the Pile.

Clamond and Mure used for their thermo-pile an alloy of zinc and antimony, with sheet iron as the second metal. Clamond's pile consists of ten elements as shown in fig. 505. The massive pieces A consist of an alloy. The iron sheets F are fastened with one end to the inner and the other end to the outer edges of the pieces A. The sheet iron plates are made to project so as to present a large cooling surface. These annular elements are placed upon each other and insulated from each other, as shown in fig. 506. The pole-clamps fastened to the outside of the battery allow the joining up of all the elements, either in series or in groups of ten. The inner junctions 1 to 19, filled in with asbestos cement, form a hollow cylindrical space, in which an earthenware tube provided with a number of small holes is placed. Gas is passed through this tube, and the different little jets heat the junctions from 1 to 19 (fig. 505), while the junctions 2 to 20 are cooled by the air. The amount of gas consumed by a battery containing five rings, each ring consisting of ten elements, according to Cazin, is 170 litres per hour; at the same time 20 grammes of copper are separated by the pile. The Paris Academy received from Th. du Moncel in May, 1879, the description of a form of the Clamond pile considerably improved, as shown in fig. 507. The pile is built over a fire-place for coke. Before

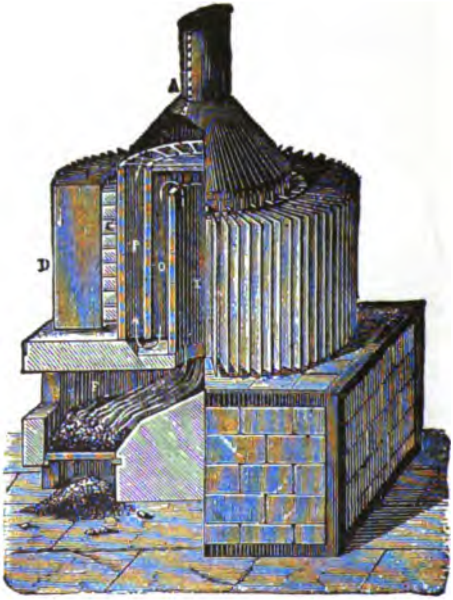


Fig. 507.—Improved Clamond's Pile.

the gases and heat can escape through the chimney A, they must pass through T O P. The elements are arranged outside the cylinder P, the iron sheets of which join the vertically-arranged copper sheets D. The latter serve to produce greater cooling at the outer junctions. According to Cazin, the height of his thermopile was 2.5 metres and the diameter 1 metre. It consisted of two separate piles, each of which contained 30 batteries of 100 elements. Each of these piles furnished a current which was capable of producing a voltaic arc equal to 40 Carcel burners. The E. M. F. of such a pile is 109 volts, with a resistance of 15.5 ohms. Both piles together are equal to 121 newly-filled Bunsen elements, and consume 10 kilogrammes of coke per hour.

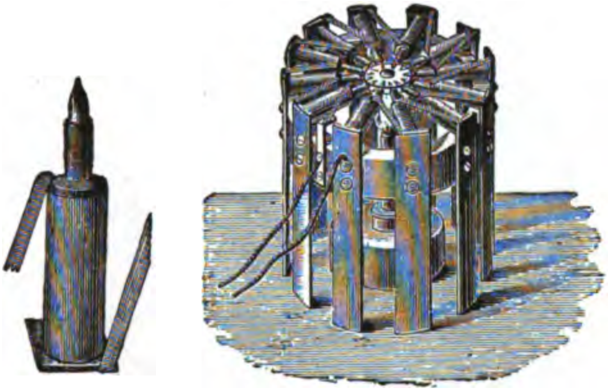


Fig. 508.—Roe's Thermo-Element.

Roe's Thermo-Element.—Fr. Roe, of Vienna, constructed his element in the following way: A copper pin (or iron coated with copper) is placed in a brass case, this again in a larger case; the larger case receives German silver wires and an alloy, which is intended to avoid the junction being screwed or soldered together. This cooling junction is formed by a brass or copper strip, to which German silver wires are soldered. An element of this kind, and the arrangement of twelve such elements to form a pile, are shown in fig. 508. The metal strips forming the cooling surfaces are screwed to a paper ring, and form the frame of the pile. With moderate heat the outer junctions are sufficiently cooled by radiation from the vertical strips. When heated to a high temperature, the metal strips are placed with the lower ends in water. A. von Waltenhofen gave the following account of such a pile:

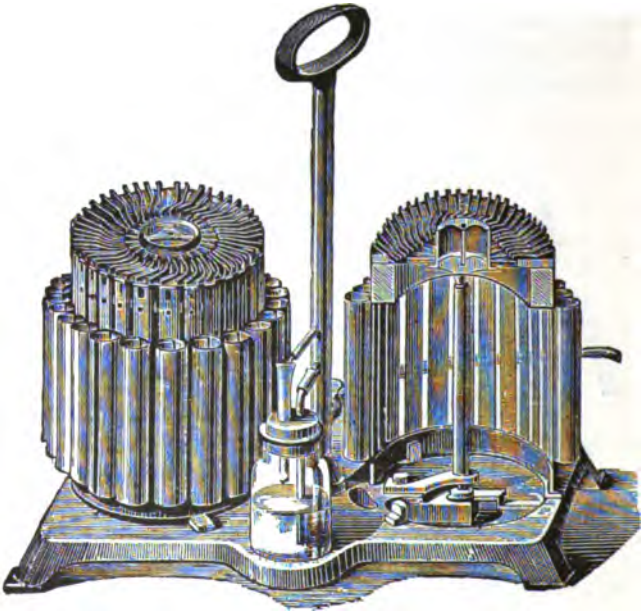


Fig. 509.—Hauck's Thermo-Pile.

"Imagine a pile consisting of 128 elements divided into four groups each. Each group represents an E. M. F. equal to that of two Daniell's elements, with a resistance of 0.8 ohm, and four groups joined in series are equal to eight Daniell's cells, with a total resistance of 3.2 Siemens' units. By joining two groups parallel and a number of these double groups in series, an E. M. F. of four Daniell's cells, with a total resistance of 0.8, is obtained.

By joining four groups parallel, the E. M. F. obtained is equal to two Daniell's cells, with limits of resistance of 0.2 ohm."

Hauck's Element.—The pile shown in fig. 509 is constructed by W. Ph. Hauck. The E. M. F. of a single element is equal to 0.1 Daniell's cell, and the resistance 0.02 Siemens' unit. Thirty elements are capable of making a platinum wire 3 centimetres long red-hot. The piles are constructed in different sizes; two or three are placed on a frame, and are very useful for school experiments and the production of galvanic deposits.

(See Secondary Cells and Batteries and Accumulators, pages 466 to 491 *ante.*)

ELECTRICITY AS A MOTIVE-POWER.

(Continuation of the same subject; see pages 402–465.)

Definitions.—By electric transmission of power is meant the utilization of electrical energy for mechanical work. Mechanical work is converted into electricity, which is conveyed to some distance, and then again, by means of a machine, re-converted into mechanical work. The great object of all inventors and mechanicians in this department is to cause as much as possible of the energy produced to be utilized for work. The electric transmission of power differs from telegraphy; here the electric current is conveyed considerable distances, and when it has arrived at its destination the current does mechanical work, but the quantity of work transmitted does not come into account.

The theory of electric transmission of power is at present far from being successfully established; and for large distances and great power no experiments have as yet been made that are practically of use. The careful experiments made by Marcel Deprez gave very interesting results from a theoretical point of view; but these would require to be practically tested before they could be made use of commercially. The solution of the problem has, however, been partially accomplished when the distances are not too great and the power required is not very large. The machines, by means of which electricity does mechanical work, are called electro-motors.

HISTORY OF ELECTRO-MOTION.

Older-Electro Motors.—It would seem that the first motor (shown in figs. 510 and 511) was constructed by Salvatore da Negro, Professor at the University of Padua, in 1830. The steel magnet A is allowed to oscillate about an axis, so that its upper end moves between the poles of the electro-magnet E (drawn separately). When a current flows through the coils of the electro-magnet, the upper end of the permanent magnet A will move so that it approaches the dissimilar, and moves away from the similar poles of the electro-magnet. If the poles of the electro-magnet are made to change constantly, the magnet A will be made to oscillate. The change of direction of the current is

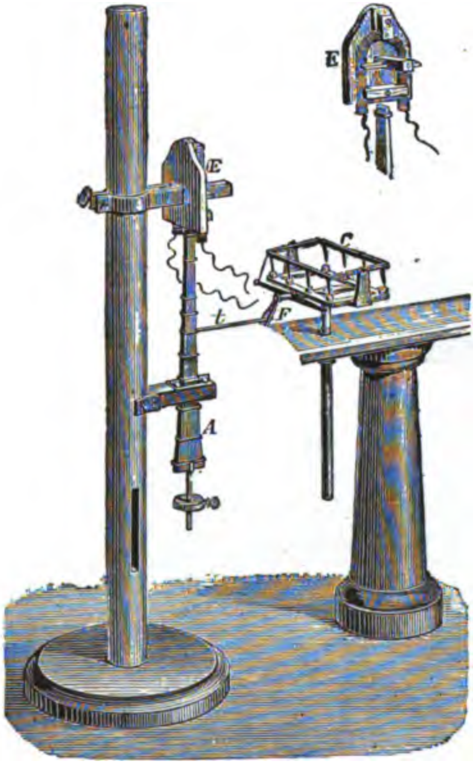


Fig. 510.—Negro's First Electro-Motor.

brought about by the commutator C, which is set in motion by the magnet A, by means of the rod *t* and forked piece F. The commutator is inserted in the same circuit as the electro-magnet, and reverses the direction of current exactly at the moment when the permanent magnet has approached the one or the other pole of the electro-magnet.

By means of the second apparatus (shown in fig. 511) a continued rotation is produced. Here the electro-magnet E influences an armature fastened to the horizontal lever L, by means of which the motion of a commutator C is also brought about. From the projection M of the lever a rod catches in the teeth of a wheel, keeping it in motion. To make this motion more uniform, pieces of wood or spokes which have balls at their ends are fastened radially upon the axis of the toothed wheel. Jacobi, the inventor of electro-deposition, published in 1834 the con-

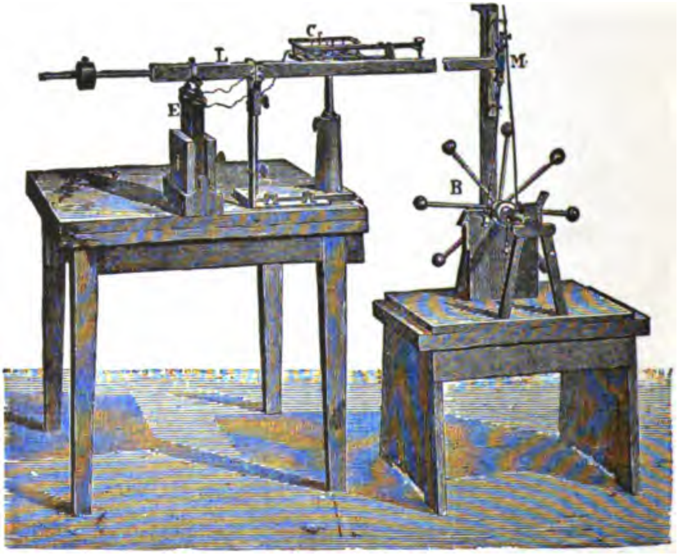


Fig. 511.—Negro's Second Electro-Motor.

struction of an electro-motor (fig. 512) which, after undergoing several alterations, was employed for propelling a vessel on the Neva. The apparatus consists of two series of horse-shoe electro-magnets fastened upon two supports; between these supports, upon a horizontal axis, is a six-armed wheel, each of whose arms carries a couple of magnets parallel to the axis. Upon the same axis is fastened a commutator of four discs, which changes the direction of the current in the coils of the electro-magnets at that moment when the straight electro-magnets are opposite the poles of the horse-shoe magnets. If the straight magnets are between two succeeding horse-shoe magnets, one of the latter influences the straight magnet with a repelling force, the other with an attracting force. When, therefore, the pole-screws of the motor are connected with a battery by means of the straight magnets and spur wheel, continued rotation is obtained. Th. du Moncel and Geraldy (in *L'Électricité comme Force Motrice*) give the following details of experiments made with this motor for propelling a vessel on the Neva. For the first experiment was used a battery of 320 Daniell elements, in which each of the copper and

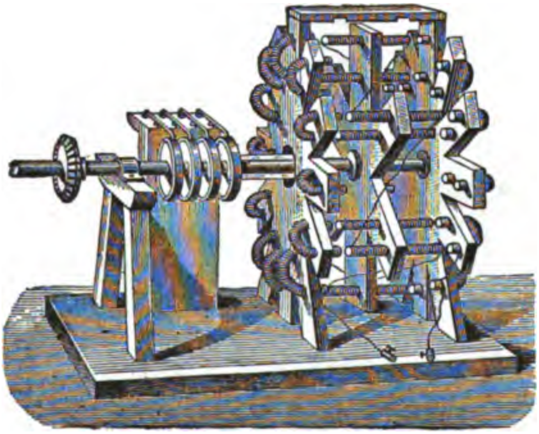


Fig. 512.—Jacobi's Electro-Motor.

zinc plates possessed a surface of 225 square centimetres. With this force the vessel moved with a velocity of 2,300 metres per hour. For the experiments in 1839, Jacobi used a battery consisting of 128 Grove elements of the same surface area of plates. With this he obtained a velocity of 4,170 metres per hour. The vessel itself measured 8.4 metres by 2.25 metres, and carried twelve persons. These experiments are said to have cost about 60,000 francs, and were paid for by the Emperor Nicholas.

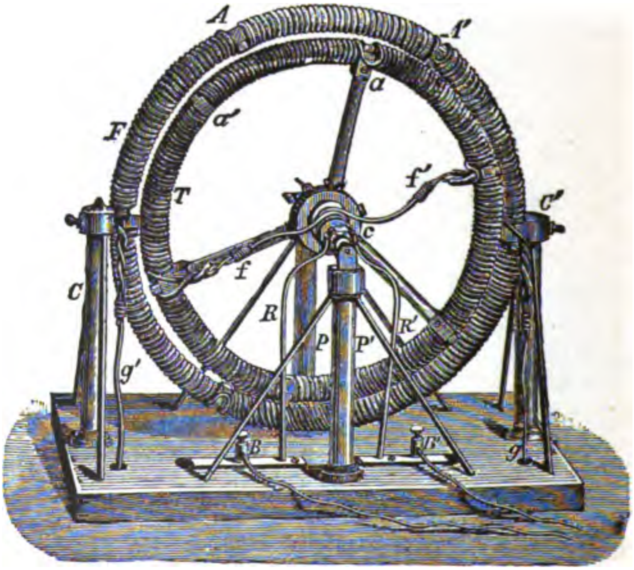


Fig. 513.—Elias's Electro-Motor.

The motor constructed by Elias in 1842 resembles Pacinotti's ring in appearance, and consists of two concentrically arranged iron rings F and T, in fig. 513, each having six groups of coils. The outer ring is fixed, and is carried by the supports C C'. By means of the six layers of wire, which are wound alternately in opposite directions, the whole ring is divided into six electro-magnets, the poles of which A A' acquire alternately north and south magnetism when a current passes through the coils. The inner ring T is constructed in a similar manner, and has also six poles *a a'*. The inner ring, however, can rotate round a horizontal axis supported by *p p'*. The commutator *c* is fastened upon the same axis, and consists of six metal strips at equal distances from each other. Strips 1, 3 and 5 are connected with the wire *f*; strips 2, 4 and 6 are connected with the wire *f'*. Over this commutator slide the springs R R', which are connected with the clamps B B'. The current for the outer ring is conveyed by means of the wires *g g'*. The motor can be used with one battery for each, or the same battery for both rings. In the first case the pole-wires of the one battery are connected with *g g'*, the pole-wires of the second with the screws B B'. The current of the first battery enters at *g*, and divides at C' into two branches, one of which flows through the coils of the upper half of the ring, and the other through the lower half; both branches unite and flow through *g'* back to the battery. The current of the second battery passes through the screw P, spring R, and the commutator, and turns off to either group 1, 3, 5; or 2, 4, 6, according as a metal strip with an even or uneven number comes under the spring R. As each of the springs slides alternately over the metal strips of the one or the other group, the direction of the current in the spirals of the inner ring has constantly to change, and this causes a continued change of the poles *a a'*, and rotation of the ring T. If, for instance, A' is a north pole, *a* has to be a south pole; *a* is therefore attracted by A', and repelled by A. If the south pole *a* has now arrived at north pole A', the south pole *a* is immediately converted into a north pole because the springs R R' have also arrived at the next metal strip, causing a reversion of the current in the coil of the movable ring. The north pole *a* is now repelled by the unchanged north pole A', and attracted by the south pole C', hence the inner ring continues its rotation in the same direction. When used with one battery the current separates into two branches, one branch flowing through the coils of the inner, the other branch through the coils of the outer ring.

Froment constructed several motors during the years 1844 to 1862, to which he gave different shapes. We shall describe only two of these; and for further information refer to Th. du Moncel and Geraldy's work, *L'Électricité comme Force Motrice.* The motor constructed in 1845 is shown in fig. 514. Four electro-magnet couples are fastened upon a frame, as shown. A wheel rotates between the poles of these electro-magnets, and carries soft iron bars fastened upon its circumference, which serve as armatures for the electros. The attraction which these electros exert upon the armatures brings about a continued rotation. The current from a battery is first conveyed to a commutator, which supplies the several magnet couples with continuous and alternating currents. The commutator consists of a series of contacts fastened to the shaft of the wheel, over which slide contact wheels or buttons pressed by springs. Thus it happens that those two electro-magnet couples are supplied with currents which are

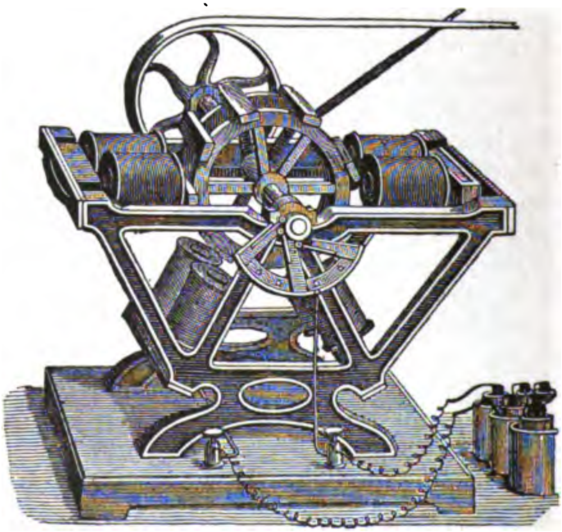


Fig. 514.—Froment's Electro-Motor.

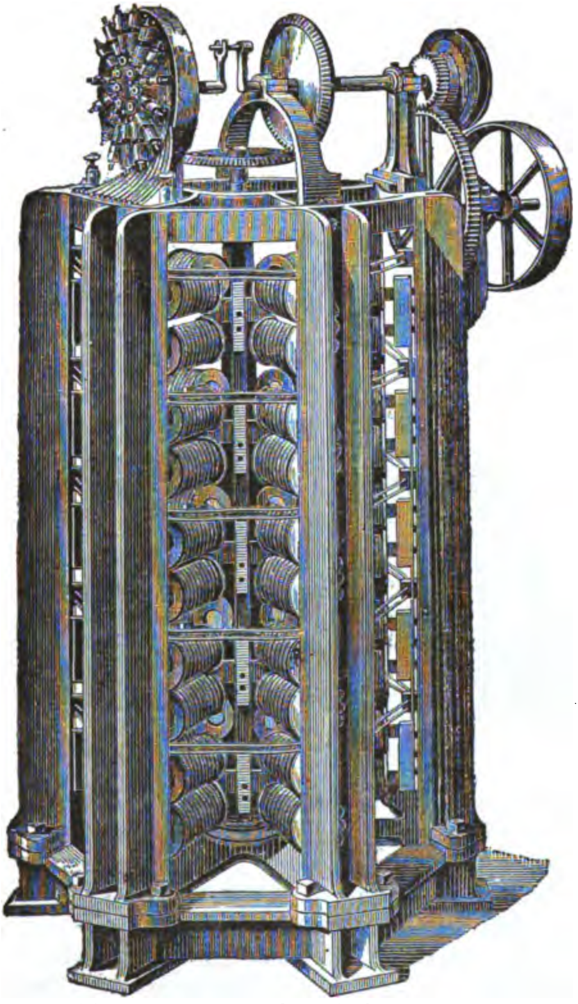


Fig. 515.—Froment's Second Electro-Motor.

being approached by the iron armatures of the wheel. This motor is still used for toys or demonstrations in physical laboratories.

The largest electro-motor which Froment constructed is shown in fig. 515. The electro-magnets are fastened to six cast-iron supports, as shown in the figure. The axis of this prism forms a vertical shaft carrying rotating soft iron armatures. To the top of the shaft is fastened a horizontal wheel, the teeth of which catch into a vertical wheel, which causes the rotation of the commutator (to the left of the figure). This consists of a series of contact rollers, which come alternately upon insulated and non-insulated portions of the disc below, when the shaft rotates. In spite of the size and solid construction of this motor, only very moderate results were obtained by means of it.

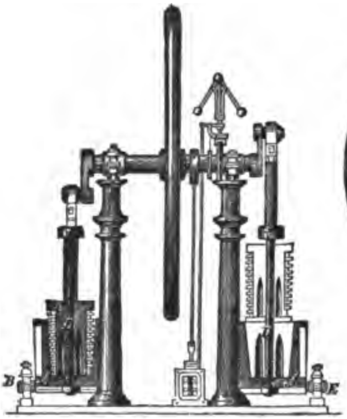


Fig. 516.—Hjorth's Electro-Motor.

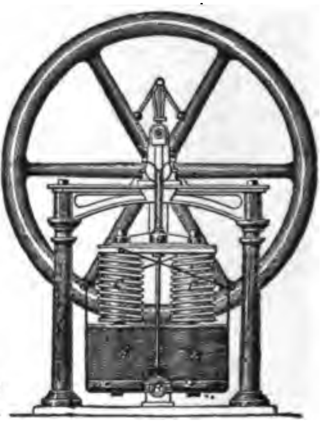


Fig. 517.—Hjorth's Electro-Motor.

Hjorth took out a patent for a motor which obtained the large medal at the London Exhibition, 1851. A representation of this motor is shown in figs. 516 and 517. The electro-magnets A A are conically hollowed inside, and fastened to the axis B, about which they rotate. The electro-magnets C C are conically shaped outside, and can slide along the guide-bars D D; their motion being transmitted by a crank to the shaft carrying the fly-wheel. The machine has a commutator which is similar in construction to the slide-valve of a steam-engine, and like it receives motion from an eccentric on the shaft. This slide allows the electric current to pass alternately into the one or other of the two electro-magnets. Owing to the construction of the magnets, the force of attraction of the horse-shoe magnets A upon C on one side is stronger than that on the other side. If in one group of magnets the movable one has finished its motion, the current in this group is reversed by means of the commutator, and produced in the other group. This causes an upward motion of magnet C in the first, and a downward motion of magnet C in the second group, so that a motion similar to that in a steam-engine is produced.

Of the older motors based on the attraction and repulsion of magnets, the ring devised by Pacinotti, a description of which has been given already, is a typical example. Of the motors for which solenoids have been used, the one constructed by Page, and shown in fig. 518, was one of the earliest. The two iron cores C and D are placed centrally over the solenoids A and B, and fastened to the connecting rods of the beam E G, which is movable about F. The continuation of the beam has at H a third connecting rod, which sets the fly-wheel in motion by means of the crank K. Upon the horizontal axis of the latter is fastened the eccentric L, which causes the coils of the solenoids A and B to be alternately inserted in the circuit of the battery. If the current flows through B, the iron core D will be drawn into the solenoid, and the left side of the beam will descend. When D has arrived at its lowest position, the current through B will be interrupted by the motion of the eccentric, and will flow through A. C is therefore drawn into A, and D rises again. Although much was expected from this motor, its efficiency is not such as to recommend it for practical purposes.

In the older electro-motors, as a rule, more or less iron matter is alternately magnetized and demagnetized, so as to attract a corresponding number of armatures or iron cores, and to cause motion. This motion, however, is not uniform, and consists of a series of impulses, which is objectionable. The defects of the older apparatus may be summed up in the following three points:

1. Impracticability of continued motion due to disconnected impulses. 2. Generation of considerable quantities of heat due to the continued change of the magnetic condition. 3. Incomplete utilization of the magnetic forces, in consequence of the arrangement of the affected parts.

The first drawback is not entirely overcome in modern machines. Even, for instance, in the Gramme ring, the motion is due to impulses, although they follow each other so rapidly that for practical purposes they might be considered continuous. The generation of heat is considerably diminished by having fixed magnets, which retain the same kind of magnetization. The armature is not now magnetized and demagnetized, but a shifting of the magnetic poles takes place. Modern machines have the

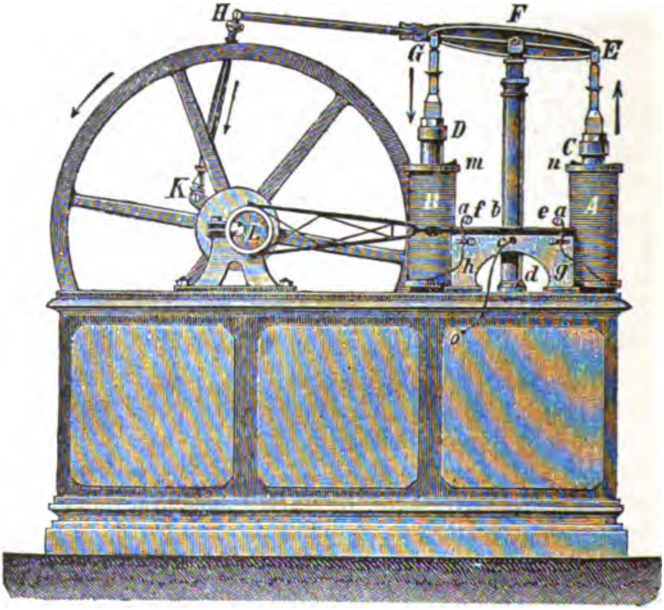


Fig. 518.—Page's Electro-Motor.

parts that are to influence each other better arranged, and their armatures rotate close to the poles.

Convertibility of Electric Machines.—If the armature of a dynamo-electric machine is made to rotate, as does the ring of a Gramme machine, currents are produced in the coils of the ring which may be utilized for the induction of the electro-magnets, and for other purposes in the external circuit. The machine, therefore, converts mechanical work into electricity. If the reverse be now adopted, *i. e.*, if the poles of such a machine are connected with the pole-wires of a source of electricity, the current of the latter will have to pass through the coils of the machine, the electro-magnets of it will come under induction, and will influence the spirals of the armature. The armature will then begin to rotate and will continue to do so as long as the current from the source of electricity flows through the coils of the machine. This motion of the armature can be transmitted by belting, etc., to a working machine, *i. e.*, a machine for mechanical work. In this case the electric current is converted into mechanical work, or the exact reverse of the first case. This property of dynamo-electric machines to convert mechanical work into electricity, and electricity into mechanical work, is called the convertibility of the machine.

It is the principle of convertibility which makes the electric transmission of power possible. It is one of the earliest known of scientific principles that if we apply heat we obtain motion (as in the steam-engine), and that, inversely, motion produces heat (as by friction). Chemical compounds are decomposed by heat; and inversely, chemical combination is accompanied by a rise of temperature. Each effect has a counter-effect. The application of this law to magneto-electric machines also was first recognized by Pacinotti, and was considered by the late James Clerk-Maxwell the most important discovery of the age. Siemens observed the convertibility in 1867. The first public experiment showing the electric transmission of force was made during the Exhibition at Vienna (1873). A Gramme machine, with permanent horse-shoe magnets, driven by a steam-engine, was used for the purpose, and the current obtained was conveyed to a second similar machine about 500 metres distant from the first. The second machine began to rotate, and was made to work a pump. The electric transmission of power for practical purposes was made use of for the first time in the laboratory of St. Thomas d'Aquin, in 1876. Cadiat, engineer of the Société du Val d'Osne, made use of it in 1878.

ELECTRIC TRANSMISSION OF POWER.

We shall now consider the electric transmission of mechanical power more closely. When a dynamo-electric machine is set in motion by a motor, and the currents produced are conveyed to a second machine, the latter may be used for doing mechanical work. The first machine, *i. e.*, the one that furnishes the current, is called the primary (French *génératrice*); the second machine, *i. e.*, the one that actually does the work, the secondary (*motrice* or *réceptrice*). When the primary machine I, fig. 519, rotates in the direction of the arrow, currents will be generated in the ring, the direction of which will be such that positive electricity will leave at a_1, and flow into the coils of the electro-magnets, and then to the secondary machine II, returning to machine I at b_1, which represents the negative pole. The current entering the secondary machine at A, flows through the first magnet-arm in the same direction as the hands of a watch move, causing south magnetism in that portion of the arm nearest A. The upper shoe will, therefore, receive north, the lower shoe south magnetism. At a_2 the current divides—one portion flows into the upper, the other portion into the lower half of the armature coils. The two branches again unite and leave the machine at b_2. We have now in the ring armature a spiral through which a current flows, that is to say, a ring-shaped electro-magnet, which is in the immediate neighborhood of the powerful magnetic poles N_2 and S_2. Let us consider in what manner the ring is magnetized by the currents that flow round it. If we go back again to a_2, where the current enters the ring, we find that the current flows clockwise in the upper half, and counter-clockwise in the lower half of the ring. We shall, therefore, have south magnetism at a_2, and north magnetism at b_2, and it follows that according to this magnetic distribution the armature will have to rotate in the direction indicated by the arrow. The north pole N_2 attracts the south pole at a_2, and repels the north pole at b_2. The south pole s_2 repels the south pole at a_2, and attracts the north pole at b_2. The resultant of these forces is a couple producing a revolution of the armature. The rotation of the ring will continue as long as machine II is supplied with current.

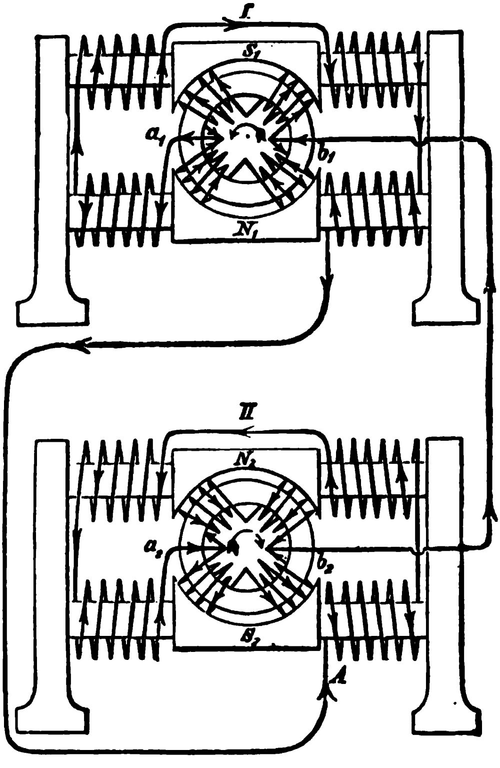


Fig. 519.—The Connection of a Dynamo and Motor.

From fig. 519 we also see that when the primary machine rotates in one direction, the secondary machine rotates in the other; and further currents are induced in the armature of the secondary machine. What will be the direction of these currents produced by the motion of the secondary machine? The answer may be obtained by reasoning as follows: The electromagnets of the primary machine possess a south pole at S, and a north pole at N. As the armature rotates from right to left, it follows therefore that the positive current will leave at a_1. If now the poles of the secondary machine had the same position, that is, if the south were above, and north below, the rotation being from left to right, the positive current would leave the machine at b_2. The position of the poles being reversed, it follows that the current induced in the armature will leave the secondary machine also at a_2; hence the primary current entering at a_2 is met by an induced current which has the opposite direction. We see then that an opposition current is generated in the secondary machine. We know that if two equally strong currents are sent through a conductor, their total effect is equal to 0. With currents of unequal strength, the difference of the two gives the final result. The strength of a current is obtained from the E. M. F., and resistance in the circuit. The E. M. F. of a dynamo-electric machine depends upon the resistance of the circuit and number of rotations of the armature. Let us suppose that two dynamo-electric machines are connected with each other, as shown in fig. 519. Let us assume that the primary machine makes 1,000 revolutions per minute, and that the speed of the secondary machine is allowed to increase gradually. If a galvanometer be included in the circuit of the two machines, the needle will show the rapid decrease of current in the machine as soon as the secondary machine begins to rotate. The counter-currents produced will increase with the speed of the secondary machine. The needle of the galvanometer will indicate a steady diminution of current, as long as the speed of the secondary machine, which we suppose has no work to do except to overcome friction, etc., continues to increase. The speed of the latter will only increase as long as the primary current is stronger than the opposition current of the secondary machine. The machines being similar in construction and equal in size, it follows that when the speed of the secondary machine has increased until it is the same as that of the primary machine the currents must be also equal, and the needle will point to zero. Let us now consider the case in which the secondary machine has to do work. The extreme case is that in which the ring of the secondary machine is held fast, *i. e.*, forcibly prevented from rotating. In this case the secondary machine cannot produce an opposition current, but acts as a simple circuit of small resistance for the primary machine, the current of which will increase rapidly to its maximum value. What then becomes of the expended energy? It is converted into heat, and the experiment can only last for a very short time without damaging the machines. Suppose now the secondary machine is allowed to do work, say to lift a load: The primary machine receives work from the steam-engine, and furnishes electric currents; the secondary machine receives electric currents, and does work. If the work the secondary machine has to do is only very slight, its speed will not be very much less than that of the primary machine, and the total current in the total circuit will be but small. If the work to be done by the machine is considerable, it will slacken its speed, and also diminish its opposition or counter-current, causing increase of current in the total circuit. If the work to be done is greater than the efficiency of the secondary machine will allow it to do, the rotation will cease altogether, and we have a repetition of the case considered above.

The behavior of the steam-engine which drives the primary machine is analogous to that of the secondary machine. If, for instance, the work of the secondary machine is only slight, the steam-engine need do but little work: the steam-engine will have to do most work when the secondary machine ceases rotating because of over-work. In each case the secondary machine returns the work transmitted by the steam-engine to the primary machine; a portion of the energy being of course lost in heat and in overcoming friction, etc. A portion of the transmitted work will be converted into heat as long as the secondary machine rotates; if the latter ceases to rotate because of the over-strain, the whole of the energy will be converted into heat. By expressing the relations here indicated between the current, counter-current, and work done in the form of equations, their consequences will probably become more clearly apparent, and therefore we will proceed to put the theory in the equational form.

THEORY OF THE ELECTRIC MOTOR.

Upon the existence and magnitude of this counter-electromotive force depends the degree to which any given motor enables us to utilize electric energy that is supplied to it in the form of an electric current. In discussing the dynamo as a generator, we have pointed out many considerations, the observance of which would tend to improve the efficiency of such generators. It is needless to say that many of these considerations, such as the avoidance of useless resistances, unnecessary iron masses in cores, and the like, will also apply to motors. The efficiency of a motor in utilizing the energy of a current depends not only on its efficiency in itself, but on another factor, namely, the relation between the electromotive force which it generates when rotating, and the electromotive force at which the current is supplied to it. A motor which itself in running generates only a *low* electromotive force cannot, however well designed, be an *efficient* or economical motor when supplied with currents at a *high* electromotive force. A good *low-pressure* steam-engine does not become more "efficient" by being supplied with *high-pressure* steam. Nor can a high-pressure steam-engine, however well constructed, attain a high efficiency when worked with steam at low pressure. Analogous considerations apply to dynamos used as motors. They must be supplied with currents of electromotive forces adapted to them. Even a perfect motor, one without friction or resistance of any kind, cannot give an efficient or economical result if the law of efficiency is not observed in the conditions under which the electric current is supplied to it.

Now it has been shown that the efficiency with which a perfect motor utilizes the electric energy of the current depends upon the ratio between this counter-electromotive force and the electromotive force of the current that is supplied by the battery. No motor ever succeeds in turning into useful work the whole of the currents that feed it, for it is impossible to construct machines without resistance, and whenever resistance is offered to a current, part of the energy of the current is wasted in heating the resisting wire. Let the symbol W stand for the whole of the electric energy of a current, and let w stand for that part of the energy which the motor takes up as useful work from the circuit. All the rest of the energy of the current, or $\mathrm{W} - w$, will be wasted in useless heating of the conductors that offer resistances.

But if we want to work our motor under the conditions of greatest economy, it is clear that we must have as little heat wasted as possible; or in symbols, w must be as nearly as possible equal to W. We have shown, mathematically, that the ratio between the useful energy thus appropriated, and the total energy spent, is equal to the ratio between the counter-electromotive force of the motor, and the whole electromotive force of the battery that feeds the motor. Let us call this whole electromotive force with which the battery feeds the motor E, and let us call the counter-electromotive force e. Then the rule is:

$$w : \mathrm{W} = e : \mathrm{E}.$$

Or, if we express the efficiency as a fraction:

$$\frac{w}{\mathrm{W}} = \frac{e}{\mathrm{E}}$$

But we may go one stage further. If the resistances of the circuit are constant, the current c observed when the motor is running will be less than C, the current while the motor was standing still. But from Ohm's law we know that:

$$c = \frac{E - e}{R}$$

$$\text{Hence } \frac{C - c}{C} = \frac{e}{E} = \frac{w}{W}$$

From which it appears that we can calculate the efficiency at which the motor is working by observing the ratio between the fall in the strength of the current and the original strength, a law of efficiency which has been known for twenty years, but has, until very lately, been strangely misapprehended.

There is a great difference between efficiency as regards speed of working and efficiency as regards economy. Jacobi's law concerning the maximum work of an electric motor, supplied with currents from a source of given electromotive force, refers to the former. The mechanical work given out by a motor is a maximum when the motor is geared to run at such a speed that the current is reduced to half the strength that it would have if the motor were stopped. This, of course, implies that the counter-electromotive force of the motor is equal to half the electromotive force given out by the battery or generator. Under these circumstances only half the energy furnished by the external source is utilized, the other half being wasted in heating the circuit. Jacobi's law does not, however, state that no motor, however perfect in itself, can convert more than 50 per cent. of the electric energy supplied to it into actual work. Dr. Siemens showed, some years ago, that a dynamo can be in practice so used as to give out more than 50 per cent. of the energy of the current. It can work more efficiently if it be not expected to do its work so quickly. Dr. Siemens has, in fact, proved that if the motor be arranged so as to do its work at less than the maximum rate, by being geared so as to do much less work per revolution, but yet so as to run at a higher speed, it will be more efficient; that is to say, though it does less work, there will also be still less electric energy expended, and the ratio of the useful work done to the energy expended will be nearer unity than before.

Hence, when rate of working without regard to economy is the main consideration, Jacobi's law must be applied; but when economy has also to be considered this law does not apply. In this case $\frac{e}{E}$ must be as large as possible, and at the same time $(E-e)$, the measure of the energy lost as heat, must be as small as possible. This can only be the case when E and e are both large. In other words, it is economy to work at high electromotive force. The importance of this matter, first pointed out by Siemens and later by Marcel Deprez, cannot be overrated.

But how shall we obtain this high electromotive force? One very simple expedient is that of driving both generator and motor at higher speeds. Another way is to wind the armatures of both machines with many coils of wire, having many turns. This expedient has, however, the effect of putting great resistance into the circuit. This circumstance may, nevertheless, be no great drawback if there is already a great resistance in the circuit; as, for example, the resistance of many miles of wire through which the power is to be transmitted. In this case doubling the electromotive force will not double the resistance, Even in the case where the line resistance is insignificant, an economy is effected by raising the electromotive force. For, as may be deduced from the equations, when $(E-e)$ is kept constant, the effect of doubling the electromotive force is to double the efficiency when the resistance of the line is very small as compared with that of the machines, and to quadruple it when the the resistance of the line is very great as compared with that of the machines. It is, in fact, worth while to put up with the extra resistance, which we cannot avoid, if we try to secure high electromotive force by the use of coils of fine wire of many turns. It is true that the useful effect falls off, *cæteris paribus*, as the resistance increases; but this is much more than counterbalanced by the fact that the useful effect increases in proportion to the square of the electromotive force.

In the recent attempt of M. Marcel Deprez to realize these conditions in the transmission of power from Miesbach to Munich, through a double line of telegraph wire, over a distance of thirty-four miles, very high electromotive forces were actually employed. The machines were two ordinary Gramme dynamos, the magnets being series-wound similar to one another; but their usual low resistance coils had been replaced by coils of very many turns of fine wire. The resistance of each machine was consequently 470 ohms, whilst that of the line was 950 ohms. The velocity of the generator was 2,100 revolutions per minute; that of the motor 1,400. The difference of potential at the terminals of the generator was 2,400 volts; at that of the motor, 1,600 volts. According to Professor von Beltz, the President of the Munich Exhibition, where the trial was made, the mechanical efficiency was found to be 32 per cent. M. Deprez has given the rule that the efficiency $\frac{w}{\mathrm{W}}$ is obtained in the case where two identical machines are employed, by comparing the two velocities at the two stations. Or

$$\frac{w}{\mathrm{W}}=\frac{n}{\mathrm{N}},$$

where N is the speed of the governor, n that of the motor.

The latest effort of inventors, as applied to motors, has been to secure uniform speed with varying demands as regards work. Dr. Sylvanus Thompson, in his now famous Cantor Lectures on this subject, has dwelt on the importance of designing motors, not simply to work with the constant electromotive force supplied at the electric mains, but also to work at uniform speeds. It is highly important, for example, in driving a lathe, and indeed many kinds of machinery, that the speed should be regular, and that the motor should not "run away" as soon as the stress of the cutting tool is removed. Now we have already explained the methods by which M. Marcel Deprez and Professor Perry have solved the problem of getting a dynamo to feed a circuit with currents, at a constant electromotive force, when driven with a uniform speed. The solution to that problem we saw consisted in using certain combinations for the field magnets, which gave an initial magnetic field, independently of the actual current furnished by the dynamo itself. This problem may be applied conversely, and motors may be built with a combination of arrangements for their field magnets, such that, when supplied with currents at a certain constant electromotive force, their speed shall be constant, whatever the work they may be doing. The one difficulty in the problem—and this is a mere matter for experiment and calculation—is to find the critical number of volts of electromotive force at which this will hold good. M. Marcel Deprez has, himself, constructed motors that run at a perfectly uniform speed, quite irrespective of the work which they may be doing. Whether the motor was lifting a load of five kilogrammes from the ground, or was letting this load run down to the ground, or ran without any load at all, the speed was the same. At the Paris Exposition Électrique of 1881 a large number of Deprez's motors were shown, running at uniform speed, and driving various machines—lathes, sewing-machines, etc.

Influence of Distance.—The total amount of heat generated in the circuit depends upon the resistance and strength of current. According to Joule's law the amount of heat generated is directly proportional to the resistance and the square of the current. If, for instance, the primary machine is three or four times the distance from the secondary machine, other conditions being equal, three or four times as much heat will be produced in the wires, and the amount of the transmitted work will diminish. But the conducting resistance is also inversely proportional to the cross section of the conductor; if, therefore, no energy is to be lost by doubling the distance, the conductor must have double the cross section; in other words, to double the distance without diminishing the current delivered to the motor, we must multiply the weight of the conducting wires by four, to treble the distance we must take nine times the weight of material, and so on. If the distance between the two machines is very great, this means is commercially impracticable, as the capital required for the material would be in no proportion to the result obtained.

The amount of heat depends further upon the strength of current. We can make the former constant in spite of the 4-, 9-, 16-fold increase in the length of the conductor, when we diminish the current to one-half, one-third, or one-fourth of its original strength. Again, the strength of current in the total circuit of the combined machines is equal to the difference of the primary and opposition currents; this difference becomes smaller as the difference of the electromotive forces of both machines becomes smaller, which can be brought about by diminishing the difference of the number of revolutions per minute in both machines. If, however, much work has to be done at long distances, by a small difference of rotation in the two machines, the electromotive forces of both machines have to be increased. This increase can be brought about either by increasing the number of revolutions, or by increasing the coils of the armature, or lastly by increasing both revolutions and coils. Theoretically therefore, we may transmit any power we please to any distance by using any given system of conductors, as for instance, simple telegraph wire for the leads. The experiments made, however, up to the present have encountered practical difficulties not easy to overcome. The reason for this is, that on the one hand, the number of revolutions cannot be increased beyond a certain limit, when the machine is not to be worn out rapidly; and on the other hand, the E. M. F. can only be increased to a certain limit, as the insulation would give way when the potentials used are too high, and the result would not only involve a loss of current, but also endanger the machines themselves. The practical use of the electric transmission of power is therefore restricted to moderate distances and moderate power.

In what, then, consists the advantage of electric transmission? First a motor is required for the primary machine, then a secondary machine, and the leads which connect the two machines are also sources of considerable expense. Why not allow the primary motor to do the work direct? If it be possible to employ the motor at the place required, it certainly would be cheaper and better to do so; but if it be impossible to bring the motor to that place at all, the work itself cannot be done without the intervention of some means of transmission. The transmission of power by means of tubes for compressed air, steam, or water, or by means of belting, etc., is only practicable for very short distances, and even for these short distances is very expensive. We will now give a series of examples of the cases in which electricity is employed for the transmission of power.

ELECTRIC RAILWAYS.

The most important applications of electric transmission of power are, at present, the electric railways. Shortly after the invention of electro-magnetic machines, Stratingh and Becker, of Gröningen (1835), and Botto in Turin (1836), constructed a magneto-electric carriage. Several others constructed similar apparatus, but as none of them were of much commercial value, we shall not go into further details respecting them. The first successful experiment was made with the electric railway exhibited by Siemens and Halske, during the Industrial Exhibition in Berlin, 1879. The railway at the Berlin Exhibition was 300 metres long. The rails formed a closed oval, so that the train returned to the point from which it started when the whole oval had been traversed. The train consisted of an electric locomotive, and a platform upon wheels. Figs. 520 and 521 show the locomotive in section. It consists of a square frame on wheels; upon this frame is fastened a Siemens machine, in such a manner that the axis of rotation is parallel to the rails. The rotation of the armature is transmitted by the toothed wheels *l*, *t*, *v* and *x*, to the wheels of the locomotive. The current from the primary machine was conveyed to the secondary machine by means of the rail N, which was insulated from the earth, and placed between the two rails which support the train. Upon this middle rail slides the rubber T, which conveys the current to the secondary machine upon the locomotive. The same experiment was repeated with equal success at different other Exhibitions, as, for instance, Frankfort. In 1880 an electric railway was shown during the Exhibition of Vienna, by Egger, in which the middle rail was left out, one of the rails representing the direct wire, and the other rail representing the return wire. In 1881 the first permanent electric railway was opened for the public; this is the railway constructed by Siemens and Halske at Lichterfelde.

An electric railway has been in use since 1880 at the works of M. Duchesne-Fournet, at Breuil en Auge (Calvados). In this large bleaching establishment machines have been used for some time for supplying current to the glow lamps, with which the establishment is lighted. Clovis Dupuy, the engineer of the establishment, resolved to utilize these machines during the day. The chemical processes which the linen has to undergo are so arranged that between every two treatments the linen has to be exposed to the air in the meadows for five or six days. Much labor, time, and money had to be expended when the linen was taken out, arranged, and brought back by hand; and hot-air or steam engines could not be employed for this purpose, on account of the smoke and dust. Dupuy, therefore, constructed

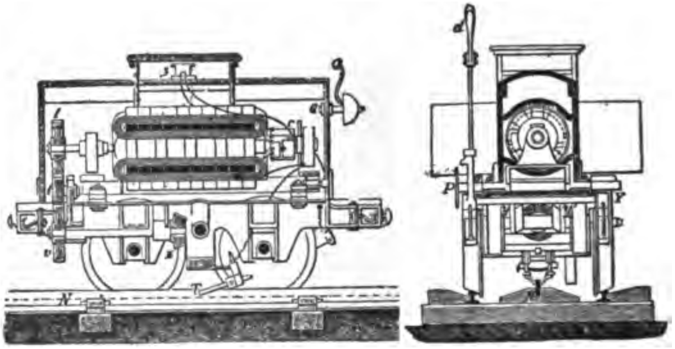


Fig. 520. Fig. 521.

Siemens and Halske's Electric Locomotive.

an electric railway, by using accumulators; the reason for not using the machine currents directly was, that the construction of the leads over damp meadows would have met with many difficulties. The installation is arranged as follows:—The rails have a total length of 2,040 metres, covering an area of about 15 hectares. The rolling-stock consists of the locomotive, the carriage for the batteries, and the carriages intended for the linen. The battery carriage bears the accumulators, of which there are six packed in baskets; each of these Faure accumulators weighs 8 kilogrammes, and it takes about seven or eight hours to charge them; for this purpose the same Gramme machines are used as are used in the evening to feed the glow lamps. The locomotive

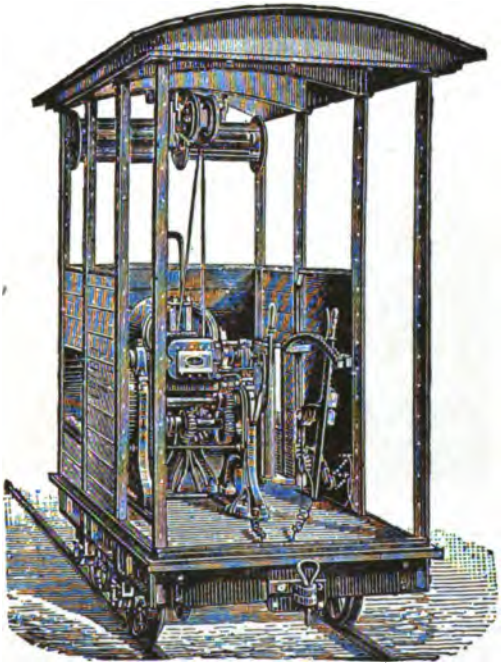


Fig. 522.—Dupuy's Locomotive.

in fig. 522 consists of a carriage containing a Siemens machine, which obtains current from the accumulators; the current is used partly for the wheels of the locomotive, and partly for the rollers and shafts which haul in the linen. By means of the levers (on the right-hand side of the figure) the locomotive can be made to stop, slacken or increase its speed; and power can be applied as required either to the wheels, or rollers and shafts. The locomotive lifts a weight of 935 kilogrammes, and draws, besides the accumulator carriage, which weighs 700 kilogrammes,

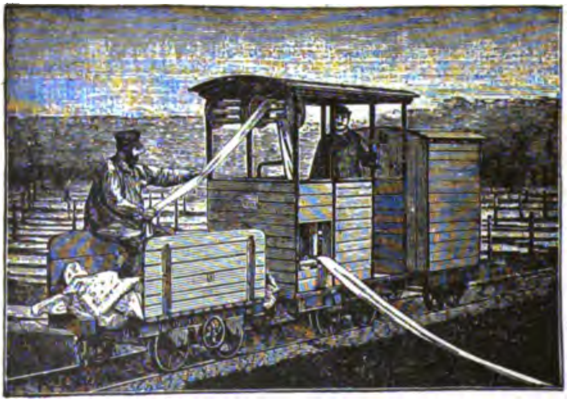


Fig. 523.—Dupuy's Electric Tramway.

six other carriages, each of which when full weighs 800 kilogrammes; that is, a total load of 6,400 kilogrammes. The train in fig. 523 is represented hauling in linen, while moving with a velocity of 12 kilometres per hour. By means of this arrangement 125 metres of linen can be collected in forty-eight seconds, or 500 metres in thirty-five minutes: a labor which was formerly done by seven persons in from four to five hours. Although, under exceptional conditions, as in the present instance, accumulators might be used with advantage, yet for most practical purposes the machine currents are used direct.

The Lichterfelde Railway, constructed by Siemens and Halske, which connects the Lichterfelde station with the Army Training School, has a length of 2½ kilometres. The primary machine, with its steam-engine, is placed at Lichterfelde. Each carriage carries a secondary machine with it. The carriages resemble tram-cars (figs. 524 and 525), and the apparatus is placed at D. The secondary machine is so arranged that its axis of rotation is parallel to the axes of the wheels of the carriage. The rotation is transmitted by means of so-called Jarolimek cords, and by the wheels R. Current is made or broken by turning a lever, and may be weakened by inserting resistances. The insertion and taking out of resistance is sufficient for the regulation of the speed of the carriages. Every secondary machine, as we have already mentioned, becomes a generator of counter-currents when in motion; a slow rotation of a secondary machine produces a weak, while rapid rotation produces a strong opposition current. A considerable force is necessary for starting the carriage; at this moment the secondary machine does not rotate at all, and consequently no opposition current is produced; as soon as the carriage begins to move, the secondary machine commences to generate opposition currents. The speed of the carriage will become uniform

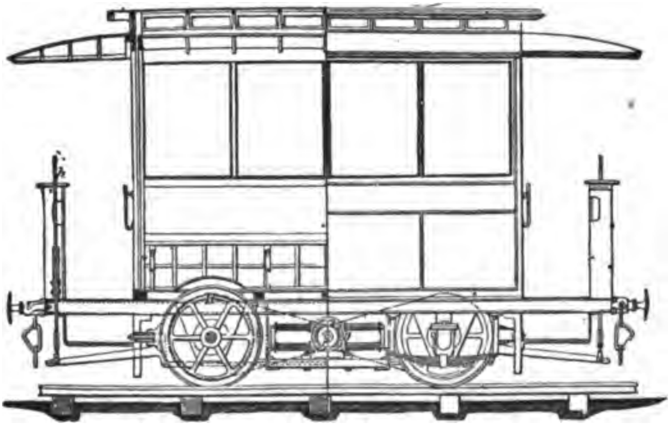


Fig. 524.—Carriage on the Lichterfelde Railway.

as soon as the difference between the primary and secondary currents has become constant. If the carriage has to ascend a hill, more power will be required, and the rotation of the secondary machine will diminish; the reverse takes place when the carriage descends, the secondary machine begins to rotate more rapidly, and its current opposes the primary current. The leads by which the connection of the primary machine with the secondary machine is brought about are the rails themselves, which rest upon wooden sleepers above the ground, except where they cross. The several rails are connected by means of elastic copper strips, so as to make sure of an uninterrupted conductor. The current flows from one of the rails into the iron ring which surrounds the wheel disc, and from here to a metal box, which is fastened to the wheel-axis; upon this slides a spring, which is really a continuation of one of the poles of the secondary machine. The current from the other rail flows into the second wheel in the same way. This method of conveying the current could not be adopted for streets, as the

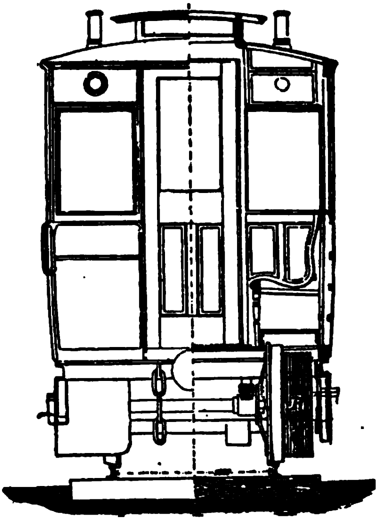


Fig. 525.—Carriage on the Lichterfelde Railway.

contact with both rails might prove dangerous to animals and men. The ordinary speed of the carriage is 20 kilometres an hour; it can, however, go at a rate of from 35 to 40 kilometres when full, *i. e.*, with twenty-six persons in it. From the 16th of May, 1881, to the 4th of January, 1882, only one carriage was used. At this time it was thought doubtful whether more carriages than one could be used; theoretically, however, it seemed possible, and was soon proved to be practicable. With double the power, and having the secondary machines joined parallel, the two carriages move with all the uniformity that can be desired.

The Electric Railway, Mödling-Brühl Line, a portion of which was in use during the winter of 1883 and 1884, and which now has a length of 3 kilometres, has the leads and return leads separate from the rails. The leads consist of iron tubes H and R, in figs. 526 and 527, which are open at the lower side, and supported by cables K and insulators J J. The insulators for the cables, as well as the insulators for the tubes, are fastened by means of iron supports to the wooden columns. The leads are connected with the secondary machines in the carriage by means

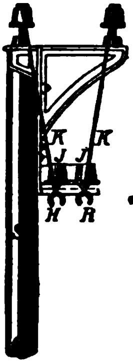


Fig. 526.
(*End Elevation.*)

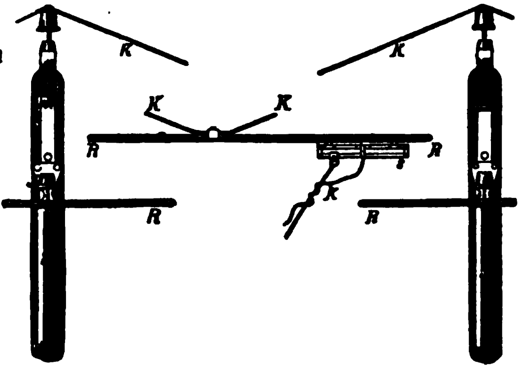


Fig. 527.—The Tubes and Cables of the Mödling-Brühl Line.
(*Side Elevation.*)

of the boats S, which slide in the tubes. Each boat is connected by means of a cord K to the carriage, and is pulled along with it. The arrangement is shown in fig. 528. R is the tube in section throughout its length. C C are the four contact pieces, of which the sliding boat consists. In order that the pieces may make good contact with the tube, each of them consists of two basins, which are pressed against the sides of the tube by springs, which are inside them. These contact pieces are connected with each other by means of the cable K, which consists of flexible copper wires. The first and last contact pieces C have prolongations P P, which protrude from the slit of the tube, and are firmly fastened to the elastic rod M; upon this slides Q, to which the rod S is fastened. To ease off the sudden pull of the ropes, a spiral spring is placed between Q and the projection. The current is conveyed from the contact boat by means of the cable U, which is fastened to H; the latter is connected with the boat by means of the copper rods N N, and the protruding pieces H. By dividing the contact boat into four pieces, and by using very elastic steel for the rod M, it is possible to pass curves of very small radius. Every carriage or train (for sometimes three carriages are fastened together) has two of such contact boats, of which the one slides in the tube which conveys the current, and the other in the returning tube.

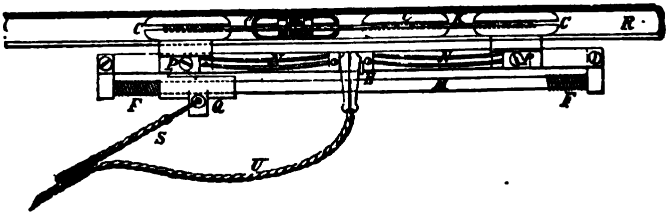


Fig. 528.—The Contact Boats.

As this railway has only a single line, it was necessary to construct points for allowing trains to pass each other. These, as constructed by Siemens and Halske, are shown in fig. 529.

When the positive lead + E arrives at the points, it divides into two portions $+ E_2$ and $+ E_3$; the negative lead $- E_1$ is similarly split up into the branches $- E_2$ and $- E_3$. At H the leads cross each other, and a short circuit would be produced, which would exclude the secondary machine of the carriage if the leads were to touch each other, and they are therefore so arranged that $+ E_3$ and $- E_2$ are not in direct communication with each other. To prevent interruption in the portions $+ e_3$ and $+ E_3$ on the one hand, and $- e_2$ and E_2 on the other, they are connected with each other by means of metal bars, which are arranged inside the wooden piece H, and are not visible in the drawing. Where the tubes $+ E_1$ and $- E_1$ divide, the tongues *z* are placed, and held in the position shown in the drawing, by means of springs. The contact boats of each carriage approaching from the left will have to slide in the tube-couple I, because the tube-couple II is closed by means of *z*. Every carriage approaching from the right will have to slide its contact boat through the tube-couple II. If now, for instance, the carriage from the right continues its course, the contact boats enter the tubes $+ E_3$ and $- E_3$; they then press upon the tongues *z z*, from behind, pushing them sideways, and allowing the carriage to continue its journey on $+ E_1$ and $- E_1$. As soon as the last contact piece has left the tongues the latter swing backwards into their former position. The carriages for the primary and secondary machines are

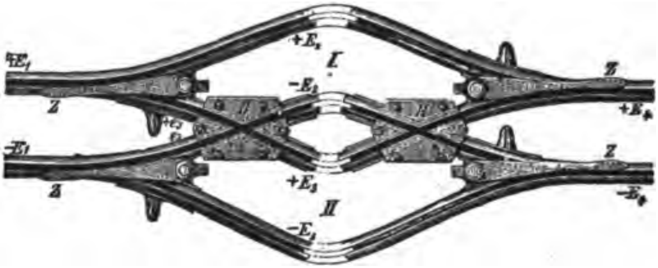


Fig. 529.—The Points.

constructed like those of the Lichterfelde Railway. A 12-horse-power locomotive, and also a 120-horse-power fixed engine, are in use.

The Portrush Railway.—The Electric Railway at Portrush, in Ireland, is of great interest, and as here the force of a waterfall is utilized, we will treat it at length, and use it for illustration of the theory. The machinery, represented in fig. 530, is described in *La Lumière Électrique*, 1883, and *The Électrician* of April 21, 1883. In the summer of 1881 Mr. W. A. Traill, late of H.M. Geological Survey, suggested to Dr. Siemens that the line between Portrush and Bushmills, for which Parliamentary powers had been obtained, would be suitable in many respects for electrical working, especially as there was abundant water-power available in the neighborhood. Dr. Siemens at once joined in the undertaking, which has been carried out under his direction. The line extends from Portrush, the terminus of the Belfast and Northern Counties Railway, to Bushmills, in the Bush Valley, a distance of six miles. For about half a mile the line passes down the principal street of Portrush, and has an extension along the Northern Counties Railway to the harbor. For the rest of the distance the rails are laid on the sea side of the country road, and the head of the rails being level with the ground, a foot-path is formed the whole distance, separated from the road by a kerbstone. The line is single, and has a gauge of three feet, the standard of the existing narrow-gauge lines in Ulster. The gradients are exceedingly heavy, being in parts as steep as one in thirty-five. The curves are also in many cases very sharp, having necessarily to follow the existing road. There are five passing-places in addition to the sidings at the termini and at the carriage depot. At the Bushmills end the line is laid for about two hundred yards along the street, and ends in the market-place of the town. It is intended to connect it with an electrical railway from Dervock, for which Parliamentary powers have already been obtained, thus completing the connection with the narrow-gauge system from Ballymena to Larne and Cushendall. About 1,500 yards from the end of the line there is a waterfall

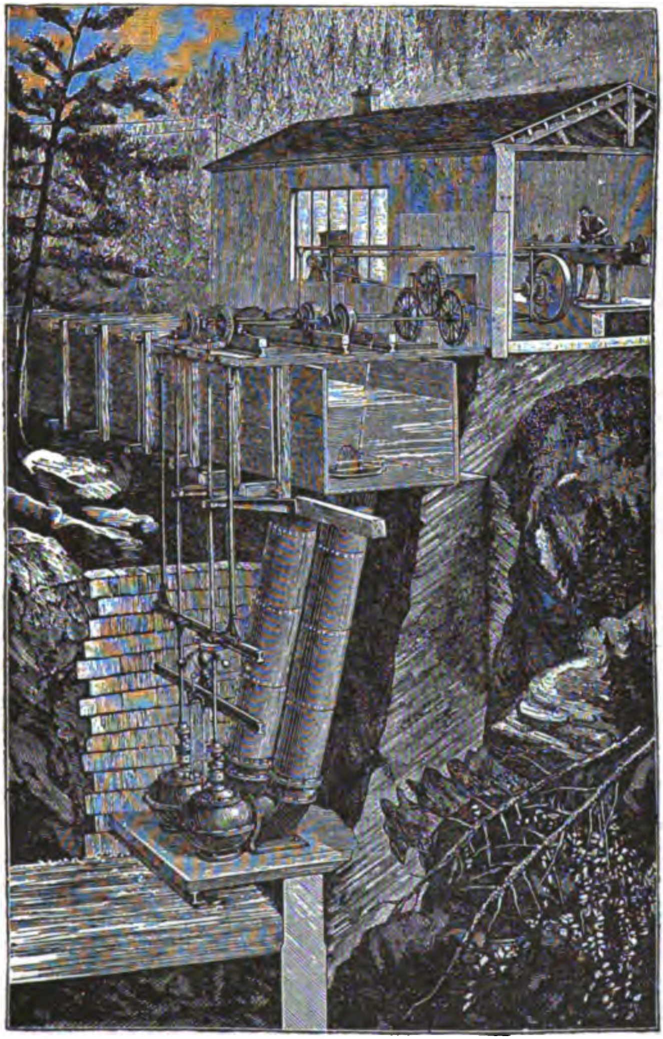


Fig. 530.—The Turbines at Portrush.

on the river Bush, with an available head of 24 feet, and an abundant supply of water at all seasons of the year. Turbines have been erected, and the necessary works executed for employing the fall for working the generating dynamo machines, and the current is conveyed by means of an underground cable to the end of the line. Fig. 530 represents the machine-house and the waterfall which supplies the natural motive-power. The primary generators (Siemens machines) receive their power from the two Alcott turbines, each of which generates 50 H. P. for 225 revolutions. The water at the higher level is led into a wooden aqueduct 2.7 metres, or 9 feet broad, and thus conveyed to the turbines through the cylinders shown in the figure, which are 1.05 metre, or 3½ feet in diameter. The speed of the turbines is automatically regulated by means of a Watt governor. It is possible to influence the regulator from the machine-house, so as to alter the rate which is automatically maintained. The shafts of the turbine carry bevelled-toothed wheels, which gear with similar wheels on horizontal shafts. At the other ends of these shafts are ordinary toothed wheels, that by their joint action keep in rotation a third wheel, which conveys the power by means of ordinary shafting to the Siemens generator within the machine-house, and which may be seen through the window in the drawing. At first the line was worked by a small steam-engine placed at the carriage depot, at the Portrush end. The whole of the constructive works have been designed and carried out by Mr. Traill, assisted by Mr. E. B. Price.

The system may be described as that of a separate conductor. A rail of tee-iron, weighing 19 lbs. to the yard, is carried on wooden posts boiled in pitch, and placed 10 feet apart, at a distance of 22 inches from the inside rail and 17 inches above the ground. The rail comes close up against the fence at the side of the track, thus forming an additional protection. The conductor is connected by an underground cable to a single shunt-wound dynamo machine, placed in the engine-shed, and worked by the turbines, or formerly by a small agricultural steam-engine. The current is conveyed from the conductor by means of two springs made of steel, rigidly held by two steel bars, placed one at each end of the car, projecting about six inches from the side: since the conducting rail is iron, while the brushes are steel, the wear of the latter is exceeding small. In dry weather they require the rail to be slightly lubricated, in wet weather the water on the surface of the iron provides all the lubrication required. The double brushes placed at the extremities of the car enable it to bridge over the numerous gaps which necessarily interrupt the conductor, to allow cartways into the fields and commons adjoining the shore. When the car arrives at one of these gaps the front brush leaves the rail, but since the back brush still touches the rail the current is not broken. Before the back brush leaves the conductor the front brush will generally have reached again to it, so that the current is not interrupted. There are, however, two or three gaps too broad to be bridged over in this way. In these cases the driver will break the current before reaching the gap, the momentum of the car carrying it the 10 or 12 yards it must travel without power. The current is conveyed under the gaps by means of an insulated copper cable carried in wrought-iron pipes, placed at a depth of 18 inches. At the passing-places, which are situated on inclines, the conductor takes the inside, and the car ascending the hill also runs on the inside, while the car descending the hill proceeds by gravity on the outside lines.

From the brushes the current is taken to a commutator, worked by a lever, which switches resistance frames placed under the car, in or out, as may be desired. The same lever alters the position of the brushes on the commutator of the secondary machine, reversing the direction of rotation. The current is not as it were turned full on suddenly, but passes through the resistances, which are afterwards cut out in part or altogether, according as the driver desires to run at part speed or full speed.

From the machine the current is conveyed through the axle-boxes to the axle, thence to the tyres of the wheels, and finally back by the rails, which are uninsulated, to the generating machine. The conductor is laid in lengths of about 21 feet, the lengths being connected by fish-plates, and also by a double copper loop, securely soldered to the iron. It is also necessary that the rails of the permanent way should be connected in a similar manner, as the ordinary fish-plates give a very uncertain electrical contact, and the earth for large currents is altogether untrustworthy as a conductor, though no doubt materially reducing the total resistance of the circuit. The secondary machine is placed in the centre of the car, beneath the floor, and through intermediate spur-gear drives by a steel chain on to one axle only. The reversing levers and also the levers working the mechanical brakes are connected to both ends of the car, so that the driver can always stand at the front and have uninterrupted view of the rails, which is, of course, essential in the case of a line laid by the side of the public road. The cars are first and third class, some open and some covered, and are constructed to hold 20 people, exclusive of the driver.

Let us now put in a form suitable for calculation the principles which Mr. Siemens has illustrated in a graphic form, and then show how these principles have been applied in the present case.

Let L be the couple measured in foot-pounds, which the dynamo must exert in order to drive the car, and w the necessary angular velocity. Then by the theory of the motor L and w are constant. Taking the tare of the car as 50 cwt., including the weight of the machinery it carries, and a load of 20 people as 30 cwt., we have a gross weight of 4 tons. Assume that the maximum rate required is that the car should carry this load at a speed of 7 miles an hour on an incline of 1 to 40. The resistance due to gravity may be taken as 56 lbs. to the ton, and the frictional resistance and that due to other causes say 14 lbs. per ton, giving at a radius of 14 in., a total resistance of 280 lbs.

The angular velocity at this radius corresponding to a speed of 7 miles an hour is 84 revolutions per minute. Hence $L = 280 \times 1\frac{1}{6} = 327$ foot-pounds, and

$$w = \frac{2\pi \times 84}{60}$$

in seconds and circular measure, in which the measure of one revolution per second is 2π.

If the dynamo be wound directly on the axle, it must be designed to exert the couple L corresponding to the maximum load when revolving at an angular velocity w, the difference of potential between the terminals being the available E. M. F. of the conductor, and the current the maximum the armature will safely stand. But when the dynamo is connected by intermediate gear to the driving wheels the product of L and w remains constant, although the two factors may be varied. In the present case L is diminished in the ratio of 7 to 1, and w consequently increased in the same ratio. Hence the dynamo with its maximum load must revolve at $84 \times 7 = 588$ revolutions per minute, and exerts a couple of $327 \div 7 = 47$ foot-pounds.

Let E_1 be the potential of the conductor from which the current is drawn measured in volts, c the current in amperes, and E the E. M. F. of the dynamo. Then E is proportional to the product of the angular velocity, and a certain function of the current. For a velocity n, let this function be denoted by $f(c)$. If the characteristic of the dynamo can be drawn, then $f(c)$ is known.

We have then

$$E_1 = \frac{w}{n} f(c) \qquad (1.)$$

If R be the resistance in circuit, by Ohm's law,

$$C = \frac{E - E_1}{R} = \frac{E - \frac{w}{n} f(c)}{R}.$$

And, therefore,

$$w = \frac{n(E - CR)}{f(C)} \qquad (2.)$$

Let a be the efficiency with which the motor transforms electrical into mechanical energy, then.

Power required $= L w = a E_1 C = a C \frac{w}{n} f(C)$.

Dividing by w,

$$L = \frac{a C f(C)}{n} \qquad (3.)$$

It must be noted that L is here measured in electrical measure, or adopting that unit given by Dr. Siemens in the British Association address, in joules. One joule equals approximately ·74 foot-pound. Equation (3) gives at once an analytical proof of the principle, that for a given motor the current depends on the couple, and upon it alone. Equation (2) shows that with a given load the speed depends upon E, the electro-motive force of the main, and R the resistance in the circuit. It show also the effect of putting into the circuit the resistance frames placed beneath the car. If R be increased until C R is equal to E, then w vanishes, and the car remains at rest. If R be still further increased, Ohm's law applies, and the current diminishes. Hence, suitable resistances are, first, a high resistance for diminishing the.current, and consequently the sparking at make and break; and secondly, one or more low resistances for varying the speed of the car. If the form of $f(C)$ be known, as is the case with a Siemens machine, Equations (2) and (3) can be completely solved for w and C, giving the current and speed in terms of L E and R. The expressions so obtained are not without interest, and agree with the results of experiment.

Telpherage.—Another method available for the conveyance of goods, though not for passengers, is that of suspending the carriages from small wheels that run on an elevated rail, called a Telpher line, the whole method being called Telpherage. The system of Telpherage, invented by the late Professor Fleeming Jenkin, in conjunction with Professors Ayrton and Perry, has for its object the automatic electrical transport, along an overhead steel rope or rod, of goods, such as minerals, ores, slate, grain, roots, manure, or, in general, any goods easily divisible into parcels of from 2 to 5 cwt., at a cost greatly less than that of cartage, without driver, guard, signalmen, or attendants. The conception of propelling by electricity a continuous stream of light trains along an elevated *single* rail or rope was due to the late Professor Fleeming Jenkin; but, as he stated in his introductory address at the University of Edinburgh, he did not see his way to carry this conception into practice until he read the account of the electrical railway exhibited by Professors Ayrton and Perry at the Royal Institution, in 1882, when the idea of subdividing the rubbed conductor into sections, and providing an *absolute block* for automatically preventing the electric trains running into one another, was first publicly described. A combination between these three gentlemen was then effected, which led ultimately to the formation of the Telpherage Company, and to the series of experiments lasting for over two years, on Telpher lines erected at Weston, in Hertfordshire, on the estate of Mr. Pryor, the chairman of the company. Various devices were worked out, forming the subject of patents, which, together with the other patents of Professors Fleeming Jenkin, Ayrton, and Perry in Telpherage, previously taken out, are possessed by the present Telpherage Company. An opportunity soon offered itself of putting the merits of the method to an actual test. The Sussex Portland Cement Company needed a line for a short distance at Glynde, to convey clay to the railway, and as, through the experiments at Weston, matters had sufficiently advanced for the erection of commercial Telpher lines, and as a tramway or road would have much interfered with the grazing and hay-growing carried on in the fields at Glynde, and as, in addition, these fields are under water during the winter, Telpherage appeared to furnish the cheapest and most suitable mode of transfer. The line is nearly a mile long, and is composed of a double set of steel rods, each 66 feet long, three-quarters of an inch in diameter, and 8 feet apart, supported on wooden posts standing about 18 feet above the ground, as seen in our illustration (fig. 531), which is from a photograph taken of the line just before it crosses the stream.

The principle of action is very simple. There are two lines of way, an up and a down line, supported on the cross-head of the posts. Each line is in pieces, and alternate segments are insulated. The problem to be solved is to maintain adjacent segments at a difference of potential, so that a train touching two adjacent pieces may receive a current which will work a motor. All the insulated sections are electrically joined by cross-over pieces at the posts, and all the uninsulated sections are similarly joined. This gives an electrical system of conductors represented diagrammatically in fig. 532, where D represents a dynamo, by which the two long conductors are maintained permanently at different potentials, as indicated by the signs + and — of each section. The wheels L and T, insulated from their trucks, are joined by a conductor which passes through a motor M. A current consequently passes from a + section to a — section whenever the train L T bridges over two sections; and this will always

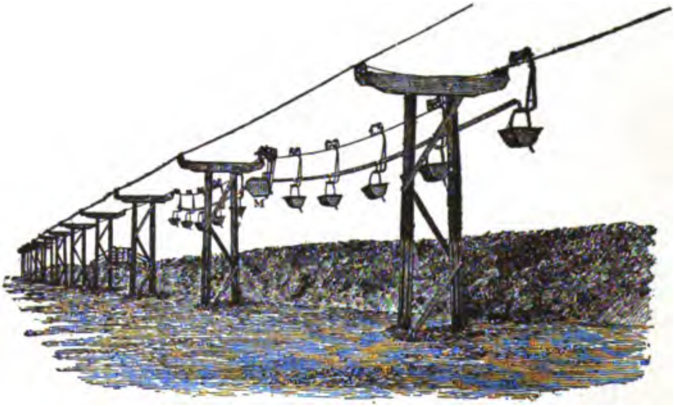


Fig. 531.—Glynde Telpherage Line.

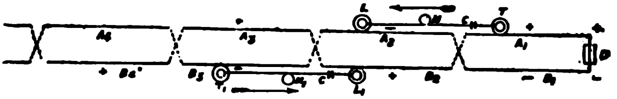


Fig. 532.—Principle of the Line.

be the case except when, for a short length of about three inches, the wheels rest on an insulated gap-piece on the saddle of the posts. The current flowing round the motor drives a shaft at a very high rate of speed; 1,600 revolutions per minute is the normal rate adopted for the line at Glynde. This shaft is connected by suitable gearing to the driving wheels of the locomotive, which hauls along the train at a speed of about four miles per hour. The train consists of a series of trucks, evenly and somewhat widely spaced, so as to distribute the load uniformly along the suspended rods. The train is either of the length of one span or two spans, consisting usually of a locomotive with five trucks in the first case, and a locomotive with ten trucks in the second case. This arrangement is adopted to neutralize the effect of the sag in the line as a resistance to the motion of the train. The initial source of power is the Ruston and Proctor engine, formerly used in the Weston experiments, and controlled by a Willan electric governor; this drives a Crompton 6 "unit" shunt-wound dynamo, D in fig. 532. The maximum difference of potential is 190 volts; the current for one train is 8 amperes, two trains need 16 amperes, and so on.

The next point of interest to be noted is the behavior of the motor at different parts of the line. The motors will not receive equal currents at various parts of the line. They will not, therefore, unless otherwise governed, develop equal horse-power. The current flowing through each motor depends on three magnitudes: A, the electro-motive force between its terminals supplied by the line; B, the back electro-motive force due to the motor itself when running; and R, the resistance of the motor. Let the current through the motor be called C, then

$$\mathrm{C} = \frac{\mathrm{A} - \mathrm{B}}{\mathrm{R}}.$$

At different parts of the line A will vary, and even at one part of the line A will not be constant unless the currents in the line are constant. B is nothing when the train is at rest, and increases as the speed increases.

If the normal current be just enough to drive the train, we shall have too little at the far end and too much at the near end. There are two ways of dealing with this difficulty. As we have said, B (the back E. M. F. of the motor) is only constant when the speed is constant, but if the train be allowed to slacken speed B falls off. A larger current will then flow through the motor, increasing the couple exerted by that motor. Conversely, if the speed of the train is allowed to increase, the value of B also increases in almost direct proportion; the current through the motor would diminish, and the effort made by the motor would also diminish. If, therefore, the mechanical resistance of the several trains were constant, and the current allowed to distribute itself subject to no special regulation, the near trains would run a little faster and the far trains a little slower. But we have in addition to provide for very unequal mechanical resistance to the haulage of the train at different parts of the line—the line may be running up-hill, down-hill, or on a level, and all varying gradients must be provided for if we are to work the trains automatically.

This automatic governing of the speed of the trains is effected in two ways—first, there is a governor attached to each motor, which interrupts the electric circuit, and cuts off the power when the speed is too high; secondly, there is a brake which comes into action if the speed increases still further.

It is the duty of the governor, shown in fig. 533, to distribute the power so as to solve this problem. The E. M. F. produced by the dynamo is made ample to provide a normal current through all the motors, which, if it flowed continuously, would do more than the necessary work at the normal speed of the motor. The governor cuts off the current from the motor for larger or shorter recurrent intervals according as more or less work is required. Thus on a moderate upward incline the current will be on for the whole time; on a steep downward incline it will be wholly cut off; on a level it will be on for, say, half the time, being taken on and off, say, five times per minute, for six seconds on each occasion. In this way the power received can be exactly fitted to the work required. This result is obtained by constructing the governor so that the diverging weights w w are in unstable equilibrium between two stops—flying out at about 1,750 revolutions per minute, and flying back at about 1,650. This is necessary to insure a sudden break of considerable magnitude in the electric circuit, to prevent the formation of a permanent electric arc when the circuit is broken. When the circuit is closed the current is conveyed across the metallic contact at *c*. When the weights fly out this contact is first broken, but no flash occurs because a connection of small resistance is maintained at *a* for a short time between two pieces of carbon, or between a rod of carbon and a rod of iron, by the rod which fits into the tube at the bottom of the apparatus being pressed outwards by a spring, and so made to follow the rod, which is attached to the moving arm, for a short distance, as the arm flies out into the dotted position. This contact at *a* is next broken, with the result of producing a brilliant electric arc for a fraction of a second, which is harmlessly employed in very slowly consuming the carbon rod.

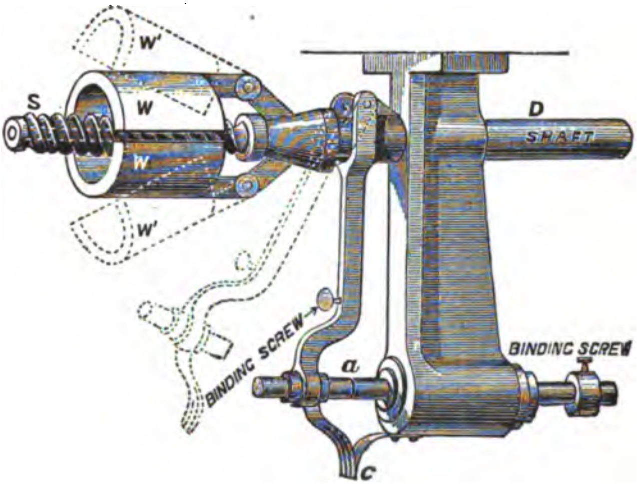


Fig. 533.—The Governor.

This method of regulating the power has been experimentally tested with complete success.

The brake is shown in fig. 534. It is simply a pair of weights W W, which, at the limiting speed, press wooden brake blocks B B against a fixed rim C with sufficient force to produce the required friction. At lower speeds the springs S S hold the blocks away from the rim. Very light diverging weights are sufficient, owing to the high speed.

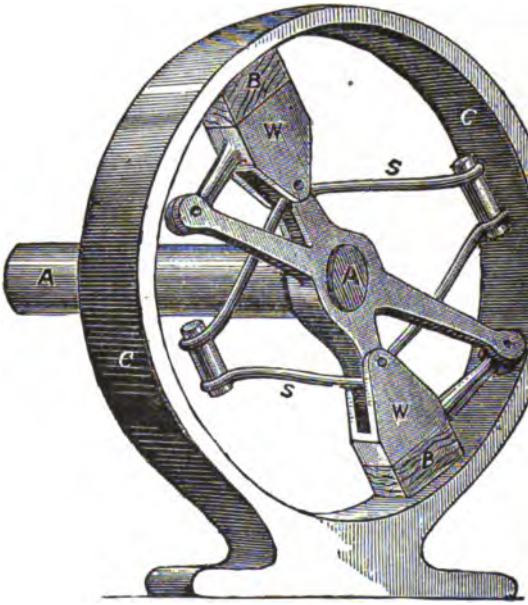


Fig. 534.—The Brake.

It is claimed that the Telpher line will find its application in all cases where the traffic is sufficient to pay interest on a small outlay, and is insufficient to pay for the construction of even the cheapest form of railway. By employing electricity the following advantages are gained: The road is simpler and cheaper, as there are no pulleys or working parts, and no second rope is required; the maintenance is cheaper; there is nothing to oil, and no working parts to wear out; the direction of the electrical road can be changed as often as is desirable, so as to follow a winding direction, an object difficult of attainment even to a moderate extent with rope haulage; the gradients in the electrical road may be as heavy as one in eight, and these gradients may vary as frequently as is desired, which is not possible, except with complicated arrangements, in rope haulage; finally, the power required will be less, except in the simplest cases of rope haulage. In addition, the electric power can easily be "tapped" *anywhere* along the line, and used for working agricultural or other machinery simultaneously with the propulsion of the Telpher trains.

As compared with light steam railways, the Telpher lines have the following advantages: They are cheaper, requiring less metal than the lightest rails. No earthworks, bridges, culverts, drains, or fences are required. No land need be purchased. Much sharper curves can be employed. No attendant is required to accompany the trains. Telpher lines crossing a farm will not materially interfere with the cultivation of the land.

Mine Railways.—As the electric transmission of power is likely to become of great importance in mines, tunnels, etc., we will next describe the mine railway at Zaukerode, Saxony. This line has a length of 700 metres, and is 260 metres under the surface of the earth. The electric locomotive moves with a velocity of about 12 kilometres per hour, carrying a load of 8,000 kilogrammes in 10 carriages. The locomotive constructed by Siemens and Halske, shown in fig. 535, has a length of 2.4 metres, a height of 1 metre, and a breadth of only 80 centimetres. It weighs 1,550 kilogrammes. The gauge is only 56.6 centimetres wide. The rotation of the armature is transmitted to the wheels of the locomotive. A dynamo-electric machine, which is driven by a small cylindrical steam-engine, is placed outside the pit for the generation of the current. The current is conveyed by means of a cable to the T-shaped iron rails fastened to the ceiling of the gallery, and a contact carriage, which slides upon the **T**-shaped rails, conveys the current to the secondary or locomotive machine. The driver can make the machine go backwards or forwards by turning a lever. In the same pit a ventilator is in use, which is also worked by electricity.

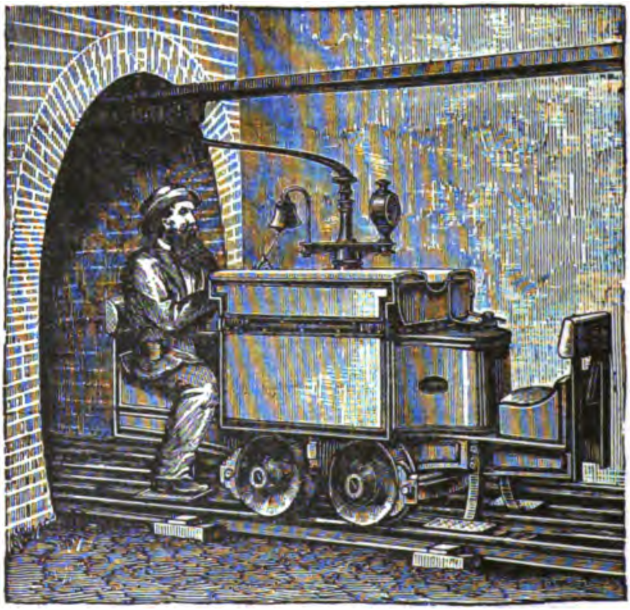


Fig. 535.—Mine Locomotive.

An electric railway for the Hohenzollern mine, near Benthen, has also been constructed by Siemens and Halske, and the use of such lines in mines appears likely to extend.

A LONG ELECTRIC RAY.

Railroad Tracks Illuminated for a Mile Ahead of the Engine. —There are two distinct views of the functions of a headlight. It may be looked upon, as it is to a very large extent abroad, as simply a signal light for the benefit of track and station men, or may be regarded as an illuminator intended to show possible obstacles on the track at a sufficient distance to enable the stopping of the train without the disastrous results of a collision. There is a well-known popular theory that the headlight is not of much use to an engineer anyhow; and if we consider the ordinary forms of reflector lamp now in use, it is not at all improbable that such a theory of inefficiency is correct. A headlight which merely shows the track a few yards in front of the engine can do little towards averting a collision, provided the train is running anywhere near the usual speed. It is to the use of electricity that we must look for a light of sufficient power to show plainly the condition of the track for a long distance in front of the train. An apparatus has been in practical use on several roads, and the results of experiments have been most gratifying. It is the invention of G. C. Pyle, of Indianapolis.

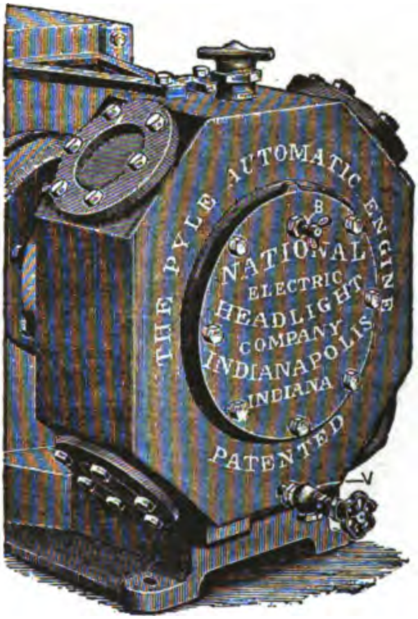


Fig. 536.

The little dynamo and engine are between the smokestack and the headlight operated by them. The engine is one of the multiple cylinder class, and is very small; perhaps the smallest engine complete and perfect in all its parts that has ever been put to practical use. Its full output is only about three horse-power, and a three-quarter inch pipe is ample to supply the steam, which is taken from the back end of the boiler, so that the throttle is always within easy reach of the engineer.

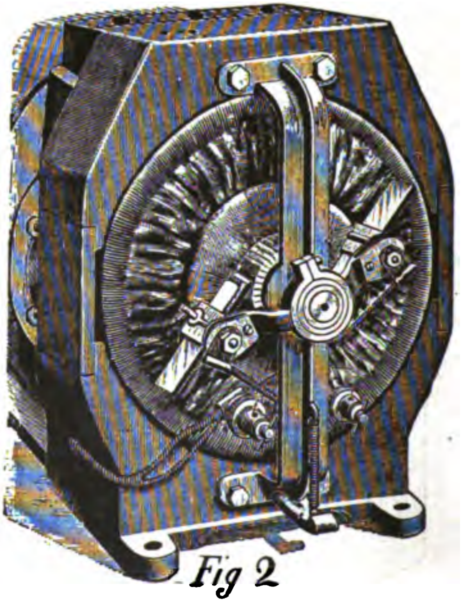


Fig. 537.

The minute engine is connected directly to the armature spindle of a diminutive dynamo in the most compact form. Designed to supply only a single arc lamp, no special regulation is necessary, and the only care required is to keep the bearings oiled and the brushes, which need never be shifted, trimmed and smooth. The total weight of the engine and dynamo together is but 650 pounds, and the combination occupies a space twenty-eight inches long, fifteen inches wide, and seventeen inches high. The normal speed is 425 turns per minute.

In fitting the apparatus to a locomotive the headlight is usually

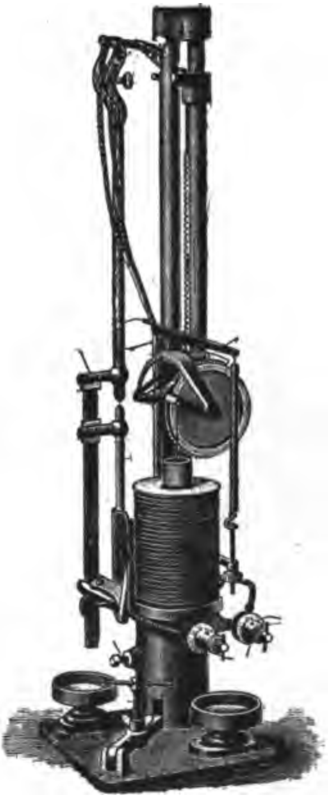
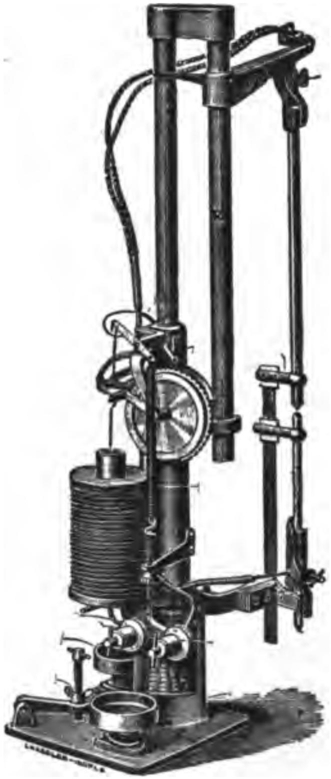


Fig. 538.



ig. 539.

moved forward a little to secure the necessary space between it and the stack for the location of the machinery. The entire plant is under complete control from the cab, as a single turn of the valve in a supply-pipe will start up the light or extinguish it when running. The lamp is of the rack-feed style. The carbons run in guides, thus steadying them at a point quite close to the arc, so that any vibration of the engine will not jar the carbons sufficiently to break them or to destroy the continuity or uniformity of the arc. The lower electrode, instead of being carbon, is a copper rod. The light given is nominally 2,000 c. p., and proves amply sufficient for railway usage, although the power could be largely enhanced if it were desirable. Electric lights are now used on the Vandalia; Cincinnati, Hamilton and Dayton; Indianapolis, Decatur and Western; Wabash; Michigan Central; Columbus, Hocking Valley and Toledo; Louisville, New Albany and Chicago; and Milwaukee, Lake Shore and Western roads.

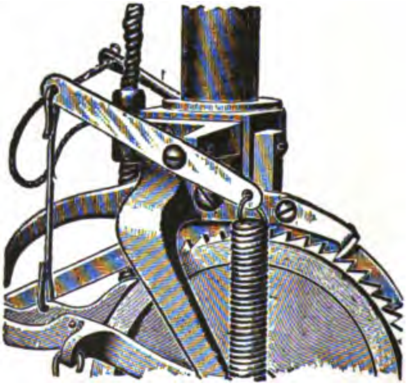


Fig. 540.

A dozen or fifteen telegraph poles in front of the engine can be distinguished regularly, even when the weather is not altogether good, and on an exceptionally clear night as many as thirty-three poles have been counted from the cab of the engine illuminated by the powerful light. Poles are about twenty-nine or thirty to the mile. Even in bad weather, when the illuminating power of the lamp could not fairly be expected to be anywhere near its maximum, the view for 1,000 or 1,200 feet ahead of the engine is substantially as good as in daylight. Small obstructions on the track could readily be made out at that distance, even by an inexperienced eye, while a great or large object would be easily visible nearly half a mile. Sitting in the cab of an engine provided with this headlight is a decidedly new sensation. Small objects like mile-posts can be readily seen at a distance of a mile in good weather, and even the joints in the rails can be seen 700 feet ahead.

Fig. 541.

Fig. 542.

The only objection which might be raised to the use of an apparatus of this kind is that which has been advanced against the electric light before by pilots. Running towards a powerful light of this kind on a double track, it might sometimes be a little difficult to distinguish landmarks by reason of the glare. But even the ordinary headlight is somewhat objectionable in this respect, and it is quite certain that additional range gained by the use of electricity will more than compensate for any additional glare. The case is much more favorable, at least, than that met by pilots, because, although there is an intensely brilliant light from the approaching engine, yet the driver's own machine is casting forward a beam of equal intensity, making the track ahead as bright as day for a long distance.

STREET ELECTRIC RAILROADS IN AMERICA.

At some future day we may publish a special work on the history of the development of electric railroads in America and elsewhere, but at the present time (1891) there are so many electric railroad enterprises before the public it would be like taking a flying shot to describe them further than to mention some of the chief in success and excellence.

DAFT's double-wire continuous metallic circuit system can be seen in active operation in Cincinnati, Ohio, and elsewhere; the THOMSON-HOUSTON poles with single arms, for suburban roads, at Rochester, N. Y.; and the same company's overhead wires for double-track road, at Washington, D. C. SPRAGUE's overhead wire system is in successful operation in Boston, Mass., St. Louis, Mo., Richmond, Va., Pittsburgh, Pa., Cleveland, O., and many other large cities. The JULIEN storage-battery system runs successfully on the Fourth Avenue road, New York, and in Baltimore, Md. Stephen D. Field has experimented, hopefully, with a system in which he "connects directly to the armature shaft a crank which, through the medium of a connecting bar, transmits its motion directly to the wheels of the locomotive." The BENTLEY-KNIGHT underground conduit system has its admirers, and several other home and foreign systems are worthy of record. We could not do justice to all the various systems in the limits of this work; we shall therefore content ourselves with having given the fundamental principles and their application, which govern all the systems.

It is amusing to note the contest for supremacy by the different electric companies; we therefore, as an illustration, make an extract from the report of a City Council meeting, relating to electric street railways, held in Philadelphia in November, 1890, which may be worth preserving.

RAPID TRANSIT.

Shall Surface Roads be worked by Wires in the Air? The Electric Overhead System for Propelling Passenger Railway Cars—The Matter Considered by Joint Committees of Councils of Philadelphia, at a Public Meeting.—The subject of rapid transit was considered at a meeting held in Select Council Chamber of the various sub-committees of the Railroad Committee of Councils, to whom were referred the different ordinances, authorizing the erection of poles and the stretching of wires on a number of streets of the city, for the purpose of propelling cars by the electric overhead system.

The corporations asking for the privilege are the Germantown (Girard avenue and Germantown) Passenger Railway Company, the Lehigh Avenue Passenger Railway Company, the Twenty-second and Allegheny Avenue Railway Company, and the Holmesburg, Tacony and Frankford Electric Railway Company.

The attendance of all persons who could impart information as to the workings of the overhead system having been requested by the Committees, as well as those who are in favor of or opposed to the different measures, there was present quite a large gathering of citizens, including a number of prominent railroad men and electricians.

When the Committee assembled, Select Councilman Thomas Green was called to the Chair, and stated that the Committee had met to give the public a chance to hear the experts on the ordinances granting privileges to the Lehigh Avenue and other chartered railway companies to use overhead electric wires for the propulsion of their cars.

The ordinance granting this privilege to the Twenty-second Street and Allegheny Avenue Passenger Railway Company was first read. It authorizes the grantees to erect standards and necessary appliances for overhead electric wires on the streets upon which it is proposed to run, such as Lehigh avenue, Huntingdon street, Somerset street, C street, Indiana avenue, Front street, K street and Venango street.

The Chair wanted a general expression of views from any of those present for and against the plan of erecting overhead wires.

"Do all these ordinances before us relate to the one subject of overhead electric wires?" asked Thomas M. Thompson.

The Chair answered affirmatively.

"Then I would suggest," said Mr. Thompson, "that we hear alternatively from those who desire to present their views for and against the proposed system."

It was then proposed to hear the views of any one present for and against the project of overhead electric wires.

Daniel H. Bates, Vice-President of the Electric Accumulator Company, was called upon, but as his theme was storage batteries as opposed to the operation of the overhead wires, he deferred to those who were to speak in favor of the overhead plan.

J. Mansfield, who represented the overhead system, stated that the storage battery system had been experimented in every known way, but had thus far proven very unsuccessful. The future, he said, might produce a storage battery which would propel the cars, but up to the present time no battery had been produced which would perform the work of running the cars. The cars depend entirely on chemical action for their motive power, but chemicals on street cars are not a very reliable source of power. The same with the motor electrical system. It is inoperative from various causes.

"The overhead system, on the other hand," he said, "had been working successfully in different parts of the country for over five years, and is constantly being improved upon. In no instance, to my knowledge, is there a city in which the overhead system is in operation where the citizens have remonstrated against its use. In Boston the system is in full operation in every part of the city and suburbs."

"Are these poles in the centre or on the sides of the streets?" asked Mr. Thompson.

"On the sides of the streets," was the response. "An ordinance limits the speed of the cars in certain sections of the city to six miles an hour, while in the suburbs they are allowed to run nine miles."

"Is it necessary to put the poles in the centre of the street?" continued Mr. Thompson. "Not absolutely necessary. The poles are erected on the sides, each twenty feet in height, and about 125 feet apart. I have never known of a single life being lost through persons coming in contact with the wires used in transmitting the power, because the voltage does not exceed 500."

"Would the wires extend over the footways?" "Not at all. The wires extend from pole to pole in the centre of the street."

"Would it be possible to have the poles on the sides of the streets without having the wire in the centre?" "I think not. Such a system was experimented with in Allegheny city, but it failed to work satisfactorily, and it was abandoned."

"What, in your opinion," asked Mr. Hall, "is the best overhead system in use at the present time?" "The Thomson-Houston system."

"Of course it is," said Mr. Thompson, "because that is the system you represent." "The gentleman asked me, and I could do nothing but answer him," was the response, which caused some merriment.

"Do the wires used in the city of Boston on the overhead system interfere with the police and fire-alarm wires in any way?" "Not to my knowledge. I never heard of the wires interfering with the city's wires."

"Is it possible to secure electric lighting from the same wires supplying the current for propelling the cars?" "Oh, yes; all the cars are lighted by incandescent lights."

"What is the character of the poles used, wood or iron?" asked Mr. Graham. "Mostly wood."

"Wouldn't iron poles be more serviceable?" "I think not. They would perhaps be more ornamental."

"You say these wires are eighteen feet from the ground," said Mr. Thompson. "We have an ordinance which prohibits the erection of a wire less than twenty-five feet from the surface. Now, is it possible to operate at that height?" "Oh, yes, by making the arm connecting with the wire larger, but not as well as when the wire is only eighteen feet from the ground."

Mr. Thompson, of the committee, suggested that Chief David Walker, the head of the Electrical Bureau of the city, should be given the opportunity to make inquiries of the representative of the overhead system.

"How do you secure the heads of your poles?" asked Mr. Walker, acting upon the privilege extended him by the Chair.

Mr. Mansfield explained the technical mechanism of attaching the wires to the poles in the overhead system.

After a few more questions of a similar character, the committee heard from Contractor William Wharton, Jr., President of the Lehigh Avenue Passenger Railway system. He said his company had been experimenting with storage batteries on their cars, in order to demonstrate the use of electric traction. After all their experiments he was personally of the opinion that the storage battery system was not financially practicable at this time.

He had earnestly tried for five years to get a successful storage-battery car, and he hoped yet to see the system made a success. The Lehigh avenue electric cars, as they are now running, have proved to be mechanically and electrically an entire success, but financially and economically they are not a success; and if the company could not avail itself of the overhead system they would have within a short time to return to the old-fashioned motive-power of horses.* They had tried a number of storage batteries, some six or seven different kinds, but none of them proved endurable under the strain of service. The wear and tear was in the charging and discharging of the current. In his opinion one of the most important methods of rapid transit was that of overhead traction. It was no experiment. It had been thoroughly demonstrated as a complete success in the principal cities.

In answer to Mr. Graham, Mr. Wharton said the Lehigh avenue road was now running three electric cars. They had four, and seven cars were in process of being built. They only ran three cars because they found it did not pay to run them. The circuit of the route is three miles and a fraction in extent. They ran at an average speed of seven miles an hour, which was about nine miles an hour in motion. The speed of the Market street cable cars west of Twentieth street was nine miles an hour, he said, by way of an example of the speed, while east of Twentieth street they run at seven miles an hour.

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* This has since been done (1891).

"The overhead system is the cheapest method of electric traction you know of?" asked Mr. Thompson. "It is the only one that has proved a success, in a money point of view."

Contrasting it with horses as a motive-power, he said that electric traction was preferable, furnishing better service. As to whether it was absolutely cheaper than horse-power he was unable to say, but he thought street-car companies would be more disposed to adopt it for many reasons as preferable to horses.

"Would you be satisfied," asked Mr. Hall, "to have a proviso inserted in your ordinance giving Councils the right to compel you to abandon the overhead system and adopt storage battery?" "I wouldn't care about going back to the storage battery system if it was no better than it is to-day. When a perfect storage battery system is found we will go back to it at once."

"Do you think there is any danger from an overhead system?" "No, sir, I do not. It all depends on the amount of the voltage. By having a system of feed wires, the voltage can be kept at 500, consequently there is no danger. There is no record of any death being due directly to the wires used in the overhead system. What the city of Philadelphia wants is a system of electric railways that will reach the outlying districts so as to keep up with the march of improvements. The Lehigh Avenue Company is perfectly willing to do everything that is possible to increase the facilities for accommodating the people living along the line of the road; and unless the privilege of operating the road by the overhead system is granted by City Councils, the corporation will be compelled to use horses, because, as I said before, the storage battery is far from being a success."

J. Levering Jones, counsel for the railway company, had visited the cities of Pittsburgh, Allegheny, Scranton and Boston within a few months. In Pittsburgh, at present, there is not a horse-car in the whole city. Scranton, since 1885, had increased from 43,000 inhabitants to 89,000, and the increase in population and in other respects is entirely attributed to the introduction of the electric system. In Boston property had increased at an immense ratio along the route of the electric cars.

W. G. Griffiths, a member of the bar, appeared before the committee on behalf of some system which will give relief to the people residing in that section, between Germantown and Chestnut Hill, not reached by the horse cars. He said it was a very good country to live in, but a very bad country to get away from when a person was in a hurry to reach the city.

Mr. Griffiths thought that the construction of an electric railroad along Germantown avenue would meet all the requirements, and said, in answer to an inquiry from one of the members of the committee, that he knew of no objection to the proposal. "The only people who can or would object," said he, "are the farmers, who would have to use another thoroughfare in bringing loads of hay to market."

Henry G. Ward, a representative of property interests, as well as some storage battery systems, presented a number of arguments against the use of overhead wires by quoting newspaper slips containing accounts of serious and fatal accidents resulting from the use of overhead wires.

Mr. Wharton took exception to the aspersions made upon the operation of the Lehigh avenue road by the speaker, and charged that Mr. Ward was present as the immediate representative of a storage battery company, who had never been able to give a satisfactory guarantee of their apparatus, and had never made any but vague promises of their utility.

Mr. Ward said, not being an officer of the storage battery company referred to by Mr. Wharton, he could not presume to answer his assertions.

Mr. Ward instanced a number of cities here and abroad where the storage battery system was in successful operation, and this argued, in spite of what Mr. Wharton said, that they must be profitable.

Mr. Wharton made some brief remarks, disclaiming any intention to disparage any system of electric traction, no matter what system it was. From his observations of the use of the storage battery on his own line, he had been charmed by the mechanical ease and smoothness with which the cars were operated and controlled. Still, in spite of all arguments that could be brought out, there had never been in this country up to this time a successful storage battery system of propelling street cars. As to the apparatus which Mr. Ward's company manufactured, it was as good as any. They had used it with entire satisfaction on the Lehigh avenue road, and had been charmed with its mechanical perfection, but yet they could not carry it out successfully, as a matter of dollars and cents.

Daniel H. Bates, vice-president of the Electric Accumulator Company, next addressed the committee. He said that his company was the only corporation that supplied storage batteries and everything else connected with the running of cars by that system. "It is quite true," said he, "that Mr. Wharton has not found the storage battery a success. Prior to 1888 we had contracts with him for furnishing the apparatus for running his cars, and if that contract was still in existence our company would be in much better condition financially, for Mr. Wharton or his company would have paid us between $100,000 and $200,000. That certainly is one good reason why the storage battery is not a success, with that company, at least. The only objection I have heard here to-day to the storage battery is its cost. We have a car which has been operated continuously and successfully for over sixty days in Dubuque."

"What is your opinion regarding the danger of an overhead system?" asked Mr. Thompson.

"I think there is very great danger to people coming in contact with the wires. Then there is the danger of lightning during a storm."

"What would be the comparative cost of storage batteries and overhead system?" "I think our plant would be most costly, but the running expense of our system would be much less. We estimate that on a level road the cost of operating, including labor and everything pertaining to the motor car would be about two cents a mile to each car, being twenty-two feet in length, and the maintenance to five cents a mile—a total of seven cents."

"Do you charge the companies a royalty for using your system?" "We do not charge a royalty."

"Isn't seven cents a mile rather high?" asked Mr. Hall. "Oh, no. The running of a sixteen-foot car in all the large cities of this State, according to the annual reports of the various companies, costs from six to nine cents a mile."

"Is there any danger from using the storage battery system?" "No danger whatever."

"How many miles can you run a car on one charge?" asked Chief Walker. "Sixty-three miles, according to Mr. Wharton's own statement."

The meeting then adjourned.

THE NEWEST ELECTRIC ROAD.

Sixty Feet under Ground—Transit Extraordinary under London's Foundation—How Londoners now Fly under Ground as Quickly as Birds in Air or Fishes in the Sea.—In November, 1890, the Prince of Wales opened the City and South London Railway, a new London rapid-transit line that is of great engineering interest and of surpassing novelty and boldness of design. Briefly stated, it is an electric railway a little over three miles in length, lying between forty and fifty feet below the surface of London streets. Both in its depth and its electrical appurtenances the line has no prototype with which it might be compared. London had two subterranean railways prior to the construction of this new line, but their first cost was enormous, their operations have not been remunerative in proportion to their capital, and the accommodations they afford are inadequate. The District Railway and the Metropolitan Railway are both subway lines lying just beneath the surface. The former cost nearly $26,000,000 for 7¼ miles of double track, and the latter cost nearly $30,000,000 for 10¼ miles. In the case of the new City and South London Road 3¼ miles have been constructed and the line fully equipped for less than $3,750,000.

Tracks Sixty Feet below the Streets.—First in point of novelty is the great depth below the surface of the City and South London Railway. This course was followed to save expenditures for land, to avoid heavy payments of compensation to property-owners whose buildings might be interfered with, and to secure economy in construction by avoidance of all foundations and surface structures. Parliament granted the use of the sub-soil of the streets free of charge ; so the railway follows the lines of the streets at its low level. The railway runs from King William street to Stockwell at present, extensions of the line being authorized and projected. The up and down lines are carried in two separate and distinct tunnels, running generally side by side, but one a few feet higher than the other, to enable the passengers from one train to pass under the platforms of the other, and thus readily reach the elevators. In Swan lane, a thirteen-foot thoroughfare, one track is placed over the other to avoid interference with foundations.

Two Parallel Tubes of Iron.—The tunnels are formed of cast-iron from beginning to end, save where the stations are built, and their diameter is 10 and 10½ feet. The tubes are formed of rings 1 foot 7 inches long, made in sections and bolted together. The tunnels were driven by means of a short cylinder, a trifle larger in its inner diameter than the exterior diameter of the cast-iron tunnel lining. This cylinder has a cutting edge, and is forced forward by hydraulic jacks, cutting a circular way into which the lining plates are fitted. The narrow space between the lining and the soil was filled with lime cement forced in under high pressure. In its course the tunnels pass beneath the bed of the Thames and through the bed of an old water-course, where loose wet gravel offered some trying obstacles for the engineers to overcome.

Elevators to Hoist a Train Load.—In addition to the two termini of the road there are four intermediate stations. At each station there is a circular shaft twenty-five feet in diameter and lined with iron rings like the tunnels. In each shaft there are two elevator cars semicircular in form, each capable of accommodating fifty passengers, or half a trainful. These cars are raised and lowered by hydraulic machinery of pattern quite similar to that of the familiar Otis hoists, and only thirty seconds are required for a car to make the ascent to the surface. Each train will accommodate 100 passengers and consists of an electric locomotive and three cars. The cars have two seats running lengthwise, as in a horse-car. Incandescent lamps in each car are fed by the same current that drives the propelling motors.

Economy of Electrical Traction.—The electrical equipment of this subterranean line is of interest hardly second to the tunnels themselves. The entire electric plant—engines, dynamos, conductors and motors—was supplied by a Manchester firm, with a guarantee that the cost of hauling the trains should not exceed seven cents per train mile. When it is borne in mind that it costs ten cents per mile to haul a London horse-car, and nineteen cents for the same work on the District Railway, the economy of the electrical system is obvious. Ten electric locomotives have already been delivered to the company, and four more are nearly completed. Each engine weighs about ten tons, and is carried on two axles. On each axle there is built the armature of an electric motor—that is, the axle forms the spindle of the motor. There is no gearing or belting of any kind, and each motor works independently of the other. The current is taken from a centre rail of steel channel, and the rails themselves serve for the return conductor. The engines are designed to run up to twenty-five or twenty-six miles an hour, and to make the entire journey of three and one-quarter miles, with four stops, at the rate of fifteen miles an hour. A uniform fare of four cents is charged for all distances on the line and fares are paid at turnstiles before entering the trains.

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